USER'S MANUAL FOR THE LAMINATED COMPOSITE INELASTIC SOLVER COMPUTER PROGRAM

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User's Manual for the Laminated composite Inelastic SOLver (LISOL) Computer Program

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Introduction

LISOL is a computer program developed at the Air Force Institute of Technology to model the nonlinear behavior of metal matrix composite laminates[1]. It uses a micromechanics approach to develop a set of constitutive relations which are automatically assembled for a specified layup. It uses the unified viscoplastic theory of Bodner and Partom to model the matrix material and assumes the fiber is thermoelastic. Temperature dependent material properties may be input for both the fiber and matrix. An interfacial failure scheme based on a statistical approach is employed to model the progressive failure of the fiber/matrix interface. Property files for the SCS6/Ti-15-3 and SCS6/Ti-β21s (sometimes referred to as TIMETAL21s) systems are currently available.

The program was designed with thermomechanical fatigue (TMF) cyclic loading in mind and to be run interactively. Therefore, it is menu driven so that the user can modify the load sequence and output from within the program. Also, symmetric layups are assumed which enhances the speed of the program, so only the ply angles required to characterize the composite need be entered and not the entire layup.

Micromechanics Background

The micromechanics approach used in the LISOL program is a modified method of cells approach [2-3] where the representative volume element for a single ply is modeled by a unit cell consisting of six regions each of uniform stress. A single fiber region, three matrix regions, and two infinitely thin interface regions, as shown in Figure 1, are

employed where the fiber and matrix are assumed to possess equivalent normal strain in the fiber direction. Also, the average strain along the external faces of the analysis cell are set equal to the ply strain. Equilibrium is accomplished by ensuring that the average stress through any cross section of the unit cell is in equilibrium with the ply stress and by forcing the stresses normal to the faces between adjacent regions to be equal. Slip between adjacent regions is allowed only in the 2-3 plane where continuity of displacements is maintained only along the external faces of the unit cell. The resulting equations for the unit cell are essentially the same as the method of cells except for the axial shear response. The original method of cells approach as proposed by Aboudi ensures equilibrium is satisfied between adjacent regions while relaxing the requirement for continuity of displacement by satisfying it only in an average sense [4]. The equations used in the LISOL program satisfy continuity of displacement in axial shear while satisfying equilibrium only in an average sense (similar to the displacement-based finite element method). All other relations are identical to the method-of-cells.

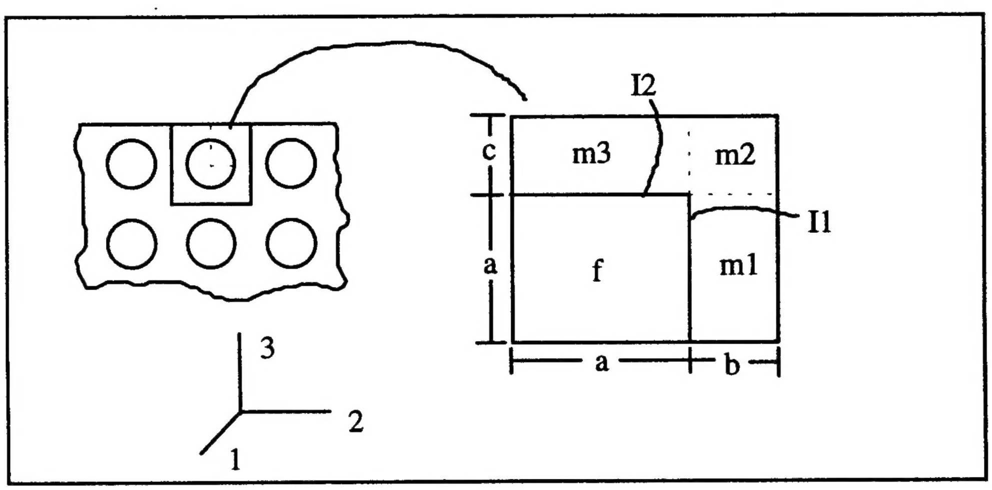


Figure 1. Schematic of the Micromechanics Model for a Single Ply

The equations for a single ply may be simplified down so that only a few normal stresses of the various regions remain coupled through a matrix equation. All the remaining normal and shear stresses may be determined by one-line equations. The general form of the equations are as follows:

$$\begin{bmatrix} & & \\ & P & \\ & & \end{bmatrix} \begin{Bmatrix} \vdots \\ \sigma_{reg} \\ \vdots \end{Bmatrix} = \begin{Bmatrix} f_{\Delta T} \\ \\ \overline{\sigma} \end{Bmatrix} - \begin{bmatrix} & & \\ & P_I & \\ & & \end{bmatrix} \begin{Bmatrix} \vdots \\ \varepsilon^{I}_{reg} \\ \vdots \end{Bmatrix} \tag{1}$$

where σ_{reg} represents the region stresses for each ply, $f_{\Delta T}$ is the thermal component of load, $\overline{\sigma}$ is the applied stress on the ply, $\varepsilon^{I}{}_{reg}$ represents the region plastic strains, and the matrices, P and P_I, simply relate the various quantities according to the given assumptions. All shear stresses as well as the remaining normal stresses are obtained from single-line equations[5].

The laminate analysis is accomplished by using the classical laminated plate theory assumption which states that any plane perpendicular to the midplane before deformation remains both plane and perpendicular to the midplane after deformation. The micromechanics equations for each ply, Eq (1), are assembled according to this assumption which results in the following general form for the laminate analysis:

$$\begin{bmatrix} & & \\ & P^{com} & \\ & & \end{bmatrix} \begin{Bmatrix} {}_{o}\varepsilon \\ \kappa \\ \sigma_{reg} \\ \vdots \end{Bmatrix} = \begin{Bmatrix} \vdots \\ f_{\Delta T} \\ \vdots \end{Bmatrix} + \begin{bmatrix} & & \\ & P_N^{com} & \\ & & \end{bmatrix} \begin{Bmatrix} N \\ M \end{Bmatrix} - \begin{bmatrix} & & \\ & P_p^{com} & \\ & & \end{bmatrix} \begin{Bmatrix} \vdots \\ \varepsilon^{p}_{reg} \\ \vdots \end{Bmatrix} \tag{2}$$

where ${}_{o}\varepsilon$ and κ are the midplane strain and curvature, respectively, σ_{reg} represents the region stresses for each ply, $f_{\Delta T}$ is the thermal component, N and M are the applied forces and moments on the laminate, $\varepsilon^{p}{}_{reg}$ represents the region plastic strains for each ply, and the matrices P^{com}, P_N^{com} and P_p^{com} are associated with the given composite layup and relate the various quantities according to the given assumptions [6].

Running the Program

The only file that need exist prior to running the program is the material property file. Once that exists, simply execute the program. The main menu will immediately come up. The desired layup is input by selecting the first submenu (*Type of Model*). The function of all other submenus are self-explanatory. The property file must be input through selecting the *Constituent Properties* submenu, and the desired load sequence may be entered either interactively or through an existing file through the *Loading* submenu. Once a solution is obtained by selecting the *Solve for Response to Applied Loading* submenu, output may be examined by selecting *Examine Results.*

Most output will be generated by selecting *Create Tables* from within the *Examine Results* submenu. The user then specifies the number of columns and what quantities are desired in those columns for output to either the screen or a file. The entire calculation may be saved and reloaded at a later date by selecting *Write existing data to a file.* The unformatted file created in this manner is a duplicate of the scratch file the program has created to this point. Reloading this file allows the user to examine results at a later date.

Material Properties

The material properties file in LISOL carries around some excess baggage due to a previous version of the program. For instance, the program flags on the second line are from the unidirectional/elastic-plastic version which possessed a more interactive capability for changing the material properties. Also, the elastic-plastic material properties (type of hardening, strain hardening parameter, and yield stress) are throwbacks from this earlier version. The elastic-plastic material model has not been carried over to the laminate analysis.

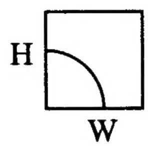
Nonlinear material models currently available in LISOL are the Bodner-Partom model with directional hardening and the original isotropic hardening Bodner-Partom model. To switch from one material model to another simply change what subroutine (BODDIR, or BODISO) is called in the subroutine VISC as well as switching the appropriate material property commented lines in VISC. The Bodner-Partom model with back stress has also been used with the program in the past. As a result, some of the values in the properties file are unique to this model. Also, if the isotropic hardening B-P model is desired, then the associated material properties should be entered using the text fields in the properties file corresponding to the B-P directional hardening model.

The LISOL program employs an interfacial failure scheme that provides for progressive failure of the interface during loading[7-8]. Three parameters are required to characterize the interface normal from its face and two are required in the tangential direction. The following paragraph gives a brief tabular description of these parameters. For a complete description of the interfacial model see the references.

Two properties files are included with the program. They are for the metal matrix composites systems SCS6/Ti-15-3 and SCS6/TIMETAL®21S.

Explanations of properties unique to LISOL:

1. Aspect Ratio. Ratio of height to width of the representative volume element.



Aspect Ratio = H/W
H is the laminate out-of-plane direction

2. σ_{IC} . Intercept on stress axis the interfacial stress-displacement curve returns to during unloading. Only applies for the normal direction from the interface.

3. S_{if_n} . Initial interfacial failure stress in the normal direction.

4. u_{lf_n} . Relative displacement of interface at which point the interface has completely failed.

5. S_{lfT}, u_{lfT} . Same as above only for the tangential direction from the interface.

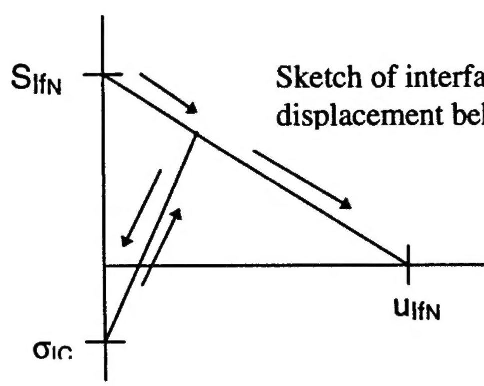


Figure 2. Interfacial Failure Model Used in LISOL

Format for LISOL Material Properties File

Note: All numerical values are in list directed read format

Name of Composite (40 characters or less) ← 1st Line
Y Y N Y (program flags - always the same, 4A2 format)
(blank line)
# of fiber points, aspect ratio, fiber volume fraction
Temp (C), E_{f11} (GPa), ν_{f12}, E_{f22}, ν_{f23}, G_{f12}
α_{f1} (°C^{-1}), α_{f2} Repeat for all fiber points
(blank line)
⋮
(blank line)
# of matrix points, type of hardening, D_0, T_{REF}
Temp (C), E_{m11} (GPa), ν_{m12}, E_{m22}, ν_{m23}, G_{m12}
α_{m1} (°C^{-1}), α_{m2}, strn hrdng param, yield strs
O_{SAT}, f1, f3, Z_0, n (B-P back stress params) Repeat for all matrix points
Z_0, n, m_1, Z_1, r_1, A_1
m_2, Z_2, r_2, A_2, Z_3 (B-P dir. hdng params)
(blank line)
⋮
(blank line)
# of interface points, σ_{IC}
Temp (C), S_{Ifn} (MPa), u_{Ifn} (normalized to fib dimension)
S_{IfT}, u_{IfT} Repeat for all interface points
(blank line)
⋮

Load Sequence

The load file in LISOL is designed for a stress-based load sequence. Unlike the material properties file, the load file may be created and modified within LISOL. It is mostly self explanatory. The load is applied in LISOL through a preload, cyclic, and post-load. To do this, two load points within the load file must be specified as defining the repeating cycle. Two distinct points that define the repeating cycle must <u>always</u> be given; even if a monotonic load is desired (simply specify a cycle number of 1).

The first load point is assumed to be the stress-free processing temperature of the composite. This point simply sets the zero stress state. Also, it is important to remember that output is only saved at the load points entered in the load file (not at any subincrements). Therefore, if output is desired at a specific point, that point must be present in the load file.

Also, the load is specified per unit length (edge load). This edge load is applied to the total thickness (sum of ply thicknesses) the user has specified in the MODEL submenu. Please note that this is applied directly to the total thickness listed in the submenu (*i.e.* you do not need to double it since it is a symmetric layup). Remember, the LISOL program assumes a symmetric layup, so the ply thicknesses entered for the model should correspond to the sum of all thicknesses for a given orientation angle.

Definition of terms:

1. Δt . Change in time from the previous load point. Any positive nonzero number may be specified for the first cycle.

2. # of subincrements . Number of increments to subdivide the load step.

3. N_X, N_Y, N_{XY} . Plate edge forces per unit length.

Format for LISOL Load File

Program flags

First line: 2A2, 4I7 format
subsequent lines: list directed

N Y # of points in file point to start cycle point to end cycle # of cycles
Δt (sec), Temp(C), N_X (MPa-mm), N_Y, N_{XY}, # of subincrements

Convergence Parameters

LISOL is a stress-based program which means it requires a stress input and solves for the strain. The associated numerical algorithm which solves the nonlinear equations contains a few convergence parameters which may be modified for a specific problem. A brief explanation of the convergence parameters is given here, but for a detailed discussion of the numerical algorithm see reference 4.

Four convergence parameters are used in the program and can individually be modified before the solution sequence. They are:

1. Multiple of elastic rates before incrementing, TOLV1. This was an effort to automate the program so it would automatically increase the number of subincrements at a given load if needed. The ratio of the calculated effective plastic strain rate to the effective elastic strain rate is checked before each subincrement. This represents a measure of the level of nonlinearity for the given point. If this ratio is above TOLV1, then the number of remaining subincrements for that load point is doubled. If the solution error message "maximum subincrements exceeded" appears, then this automation feature is causing a problem. It may be shut-off by increasing TOLV1 arbitrarily high. If the error message still appears, then the solution is diverging.

2. Instability convergence factor, TOLV2. This factor controls the rate of convergence. A higher number produces a slower but more stable convergence. From experience the default value of 15 is satisfactory for almost all cases.

3. Convergence error tolerance, TOLV3. This value controls when to stop iterating and apply the next load increment. If the change in the calculated effective plastic strain rate from the present to the previous iteration divided by the effective elastic strain rate is less than TOLV3, then the iteration ceases.

4. Amount above interface failure before incrementing, TOLV4. This performs a similar function for interfacial failure as TOLV1 does for viscoplasticity. If the calculated interfacial stress is more than this amount above the interfacial failure stress, then the remaining number of subincrements for that load point is doubled.

The stress-based numerical solution is advantageous for many cyclic type loadings because most cyclic tests are stress-controlled. However, some convergence problems can occur with stress-based solutions. For instance, the stress strain curve not only flattens out, but also begins to decrease for many materials. A stress-based program cannot converge in such cases. A way to get around this for monotonic loading is to alternatively increase and decrease the load steps to approximate the stress strain curve as shown below.

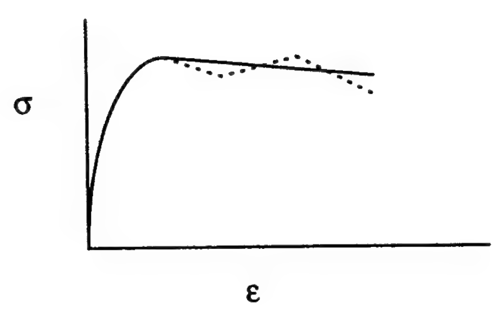


Figure 3. Approximating a Decreasing Stress-Strain Curve With a Stress-Based Algorithm.

Also, there seems to be a problem with the B-P directional hardening constants for both the Ti-β21s and Ti-15-3 materials under large reversed viscoplastic strain. For instance, after several cycles in some high stress cyclic loading cases, the solution fails to converge during unloading. Little can be done about this problem without using a different material model or reevaluating the viscoplastic constants.

Memory Considerations

Before running any calculations of large numbers of cycles (in the thousands), please check the available memory on your machine. All the composite information for each load point is written to a scratch file while the program is running. If LISOL consumes all the available memory, it will crash and possibly cause other applications to crash. To avoid this, first run LISOL for a smaller number of cycles (e.g. 500). Save the results to an unformatted file, and multiply the size of this file appropriately. If the machine does not have at least this amount of memory remaining along with a substantial buffer, do not attempt to run the program for such a high number of cycles without freeing up some memory.

Summary

As indicated by the material property files given with the program, the main use of the LISOL code to date has been in the area of titanium-based metal matrix composites. However, any continuously reinforced composite system may be analyzed with the code

if the appropriate material properties are used. Also, the code was created as part of a research effort, and as such, is a research code. Therefore, it is not maintained and updated like a commercial code. Any comments or questions concerning the code as well as requests for the code should be directed to the Department of Aeronautics and Astronautics, Air Force Institute of Technology, 2950 P Street, Wright-Patterson AFB, OH, 45433-7765.

References

[1] Robertson, David D., "A Nonlinear Three-Dimensional Micromechanics Model for Fiber-Reinforced Laminated Composites," Ph.D. Dissertation, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, AFIT/DS/AA/93-3, November 1993.

[2] Aboudi, J. "Micromechanical Analysis of Composites by the Method of Cells," *Applied Mechanics Review*, **42**(7), July 1989, pp.193-221

[3] Robertson, D. D., and Mall, S., "Micromechanical Relations for Fiber-Reinforced Composites Using the Free Transverse Shear Approach," *Journal of Composites Technology & Research*, **15**(3), (1993), pp. 181-192.

[4] Aboudi, J. "Closed Form Constitutive Equations for Metal-Matrix Composites," *International Journal of Engineering Science*, **25** (1987), pp.1229-40

[5] Robertson, D. D., and Mall, S., "Micromechanical Analysis for Thermoviscoplastic Behavior of Unidirectional Fibrous Composites," *Composites Science and Technology*, **50**, 1994, pp. 483-496.

[6] Robertson, D. D., and Mall, S., "A Nonlinear Micromechanics Based Analysis of Metal Matrix Composite Laminates," *Composites Science and Technology*, **52**(3), (1994), pp. 319-331

[7] Robertson, D. D., and Mall, S., "Micromechanical Analysis of Metal Matrix Composite Laminates With Fiber/Matrix Interfacial Damage," *Composites Engineering*, **4**(12), 1994, pp 1257-1274

[8] Robertson, David D., and Mall, Shankar, "Analysis of the Thermo-Mechanical Fatigue Response of Metal Matrix Composite Laminates With Interfacial Normal and Shear Failure," *Thermo-Mechanical Fatigue Behavior of Materials: 2nd Volume, ASTM STP 1263*, Michael J. Verrilli and Michael G. Castelli, Eds., American Society for Testing and Materials, Philadelphia, 1996, pp. 236-251

Appendix - A, Material Property Files

<u>Property File for SCS6/Ti-15-3</u>

```
SCS6/Ti-15-3
 Y Y N Y

 10., 1.0, 0.35
 21.11,  393.,  0.2,  393.,  0.2,  157.2
 3.52911e-06,  3.52911e-06

 93.33,  390.,  0.2,  390.,  0.2,  156.0
 3.56562e-06,  3.56562e-06

 204.44,  386.,  0.2,  386.,  0.2,  154.4
 3.58091e-06,  3.58091e-06

 315.56,  382.,  0.2,  382.,  0.2,  152.8
 3.61545e-06,  3.61545e-06

 426.67,  378.,  0.2,  378.,  0.2,  151.2
 3.67056e-06,  3.67056e-06

 537.78,  374.,  0.2,  374.,  0.2,  149.6
 3.73890e-06,  3.73890e-06

 648.89,  370.,  0.2,  370.,  0.2,  148.0
 3.81488e-06,  3.81488e-06

 760.00,  365.,  0.2,  365.,  0.2,  146.0
 3.89375e-06,  3.89375e-06

 871.11,  361.,  0.2,  361.,  0.2,  144.4
 3.97195e-06,  3.97195e-06

 1093.3,  354.,  0.2,  354.,  0.2,  141.6
 4.09657e-06,  4.09657e-06


 7,  0.,  10000.,  23.
 25.,  91.8,  0.36,  91.8,  0.36,  33.75
 8.4800e-06,  8.4800e-06,  0.,  0.
 0.,  0.,  0.,  0.,  0.
 1200.,  4.5,  0.,  1300.,  3.,  1.0e-08
 .005,  1200.,  3.,  1.0e-08,  250.
```

```
315.,  80.44,  0.36, 80.44,  0.36,  29.57
9.16e-06,  9.16e-06,  0.,  0.
0.,  0.,  0.,  0.,  0.
1070.,  2.9,  0.,  1300.,  3.,  4.4e-06
.04,  1070.,  3.,  4.4e-06,  454.

427.,  77.5,  0.36,  77.5,  0.36,  27.5
9.4e-06,  9.4e-06,  0.,  0.
0.,  0.,  0.,  0.,  0.
1020.,  2.7,  0.,  1300.,  3.,  1.0e-05
.05,  1020.,  3.,  1.0e-05,  550.

482.,  72.24,  0.36,  72.24,  0.36,  26.56
9.71e-06,  9.71e-06,  0.,  0.
0.,  0.,  0.,  0.,  0.
850.,  1.6,  0.,  1300.,  3.,  1.
5,  850.,  3.,  1.0,  1100.

566.,  64.4,  0.36,  64.4,  0.36,  23.68
9.98e-06,  9.98e-06,  0.,  0.
0.,  0.,  0.,  0.,  0.
700.,  1.05,  0.,  1300.,  3.,  0.79
8.,  700.,  3.,  0.79,  2400.

649.,  53.00,  0.36,  53.00,  0.36,  19.49
10.260e-06,  10.260e-06,  0.,  0.
0.,  0.,  0.,  0.,  0.
600.0,  0.7,  0.,  1300.,  3.,  0.2
10.00,  600.0,  3.,  0.2,  3800.

900.,  25.00,  0.36,  25.00,  0.36,  9.19
10.5e-06,  10.5e-06,  0.,  0.
0.,  0.,  0.,  0.,  0.
150.,  0.5,  0.,  1300.,  3.,  0.2
20.,  150.,  3.,  0.2,  5000.


3, -75.
25., 95.,  .04
130.,  .20

538., 80.,  .04
75.,   .05

650., 75.,  .04
60.,   .05
```

Property File for SCS6/TIMETAL®21S

```
SCS6/TIMETAL21s
 Y Y N Y

 10., 1.4, 0.35
 21.11,  393.,  0.25,  393.,  0.25,  157.2
 3.52911e-06,  3.52911e-06

 93.33,  390.,  0.25,  390.,  0.25,  156.0
 3.56562e-06,  3.56562e-06

 204.44,  386.,  0.25,  386.,  0.25,  154.4
 3.58091e-06,  3.58091e-06

 315.56,  382.,  0.25,  382.,  0.25,  152.8
 3.61545e-06,  3.61545e-06

 426.67,  378.,  0.25,  378.,  0.25,  151.2
 3.67056e-06,  3.67056e-06

 537.78,  374.,  0.25,  374.,  0.25,  149.6
 3.73890e-06,  3.73890e-06

 648.89,  370.,  0.25,  370.,  0.25,  148.0
 3.81488e-06,  3.81488e-06

 760.00,  365.,  0.25,  365.,  0.25,  146.0
 3.89375e-06,  3.89375e-06

 871.11,  361.,  0.25,  361.,  0.25,  144.4
 3.97195e-06,  3.97195e-06

 1093.3,  354.,  0.25,  354.,  0.25,  141.6
 4.09657e-06,  4.09657e-06


 16,  0.,  10000.,  23.
 23.,  112.,  0.34,  112.,  0.34,  41.79
 6.3100e-06,  6.3100e-06,  0.,  0.
 0.,  0.,  0.,  0.,  0.
 1550.,  4.8,  0.,  1600.,  3.,  0.
 0.35,  1550.,  3.,  0.,  100.

 260.,  108.,  0.34,  108.,  0.34,  40.30
 7.2600e-06,  7.2600e-06,  0.,  0.
```

```
0.,  0.,  0.,  0.,  0.
1300.,  3.5,  0.,  1600.,  3.,  0.
0.35,  1300.,  3.,  0.,  300.

315.,  106.133,  0.34,  106.133,  0.34,  39.60
7.483e-06,  7.483e-06,  0.,  0.
0.,  0.,  0.,  0.,  0.
1250.5,  3.054,  0.,  1600.,  3.,  0.000044
1.5,  1250.5,  3.,  0.000044,  390.

365.,  104.089,  0.34,  104.089,  0.34,  38.84
7.684e-06,  7.684e-06,  0.,  0.
0.,  0.,  0.,  0.,  0.
1205.4,  2.649,  0.,  1600.,  3.,  0.000274
2.55,  1205.4,  3.,  0.000274,  500.

415.,  101.74,  0.34,  101.74,  0.34,  37.96
7.884e-06,  7.884e-06,  0.,  0.
0.,  0.,  0.,  0.,  0.
1160.4,  2.243,  0.,  1600.,  3.,  0.001304
3.60,  1160.4,  3.,  0.001304,  660.

465.,  99.085,  0.34,  99.085,  0.34,  36.97
8.085e-06,  8.085e-06,  0.,  0.
0.,  0.,  0.,  0.,  0.
1115.3,  1.838,  0.,  1600.,  3.,  0.00503
4.64,  1115.3,  3.,  0.00503,  960.

482.,  98.113,  0.34,  98.113,  0.34,  36.60
8.150e-06,  8.150e-06,  0.,  0.
0.,  0.,  0.,  0.,  0.
1100.0,  1.700,  0.,  1600.,  3.,  0.0076
5.00,  1100.0  3.,  0.0076,  1100.

500.,  97.045,  0.34,  97.045,  0.34,  36.21
8.225e-06,  8.225e-06,  0.,  0.
0.,  0.,  0.,  0.,  0.
1089.3,  1.500,  0.,  1600.,  3.,  0.01165
5.763,  1089.3  3.,  0.01165,  1300.

525.,  95.497,  0.34,  95.497,  0.34,  35.63
8.325e-06,  8.325e-06,  0.,  0.
0.,  0.,  0.,  0.,  0.
1074.4,  1.280,  0.,  1600.,  3.,  0.0203
6.822,  1074.4  3.,  0.0203,  1670.
```

```
550.,  93.873,  0.34,  93.873,  0.34,  35.03
8.426e-06,  8.426e-06,  0.,  0.
0.,  0.,  0.,  0.,  0.
1059.5,  1.100,  0.,  1600.,  3.,  0.0342
7.881,  1059.5  3.,  0.0342,  2100.

575.,  92.172,  0.34,  92.172,  0.34,  34.39
8.526e-06,  8.526e-06,  0.,  0.
0.,  0.,  0.,  0.,  0.
1044.6,  0.97,  0.,  1600.,  3.,  0.0559
8.941,  1044.6  3.,  0.0559,  2600.

600.,  90.395,  0.34,  90.395,  0.34,  33.73
8.626e-06,  8.626e-06,  0.,  0.
0.,  0.,  0.,  0.,  0.
1029.8,  0.82,  0.,  1600.,  3.,  0.0887
10.00,  1029.8  3.,  0.0887,  3700.

650.,  86.612,  0.34,  86.612,  0.34,  32.31
8.830e-06,  8.830e-06,  0.,  0.
0.,  0.,  0.,  0.,  0.
1000.0,  0.74,  0.,  1600.,  3.,  0.2100
10.00,  1000.0  3.,  0.2100,  3800.

760.,  77.216,  0.34,  77.216,  0.34,  28.81
9.270e-06,  9.270e-06,  0.,  0.
0.,  0.,  0.,  0.,  0.
600.0,  0.58,  0.,  1600.,  3.,  1.00
15.00,  600.0  3.,  1.00,  4000.

815.,  71.964,  0.34,  71.964,  0.34,  26.87
9.490e-06,  9.490e-06,  0.,  0.
0.,  0.,  0.,  0.,  0.
300.0,  0.55,  0.,  1600.,  3.,  2.00
30.00,  300.0  3.,  2.00,  4100.

900.,  63.122,  0.34,  63.122,  0.34,  23.55
9.779e-06,  9.779e-06,  0.,  0.
0.,  0.,  0.,  0.,  0.
300.0,  0.55,  0.,  1600.,  3.,  2.00
30.00,  300.0  3.,  2.00,  4300.


1, -5.
25., 3., .01
   100., .01
```

Appendix - B Program Listing

```
C
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C     LISOL stands for Laminated composite Inelastic SOLver.
C     It is a three dimensional nonlinear micromechanics model that
C     provides solutions for nonlinear composite laminate
C     behavior.
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
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C
C Programmed by:
C
C  David D. Robertson (513) 255-3636 ext. 4597
C  Air Force Institute of Technology
C  Wright-Patterson AFB, OH  45433-7765
C
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C----------------------------------------------------------------
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C
      PROGRAM LISOL

      REAL NUF12(40),NUF23(40),NUM12(40),NUM23(40),NX(9999),NY(9999),
     > NXY(9999)

      CHARACTER FIB*1,MATE*1,MATP*1,MATV*1,TCHARP*1,TCHARV*1,
     >COMP*40, ECHAR*1,LCHAR*1
```

```
      COMMON/TYPEMOD/NA,NUMPLY,ZPOS(7),ANGLE(6)

      COMMON/MATERIAL/NUF12(40),NUF23(40),NUM12(40),NUM23(40),GM12(40),
     >EM22(40),EM11(40),AR,VF,GF12(40),EF22(40),EF11(40),HPRAMPTS(40),
     >YSPTS(40),TEMPROPF(40),TEMPROPM(40),NTEMF,NTEMM,HD,ALPHAF1(40),
     >ALPHAF2(40),ALPHAM1(40),ALPHAM2(40),OSAT(40),F1(40),F3(40),Z0(40),
     >BN(40),DNOT,Z0D(40),BND(40),BM1D(40),Z1D(40),R1D(40),
     >A1D(40),BM2D(40),Z2D(40),R2D(40),A2D(40),Z3D(40),TEMPREF,NTEMI,
     >SIC,TEMPROPI(40),SIFN1(40),UIFN1OA(40),SIFT1(40),UIFT1OA(40)

      COMMON/LOADING/NC1,NC2,NUMP,NUMCYC,DT(9999),TEMP(9999),NX(9999),
     >NY(9999),NXY(9999),M(9999)

      COMMON/ELASTPROP/SSF11(40),SSF22(40),SSF12(40),SSF23(40),
     >SSF44(40),SSM11(40),SSM22(40),SSM12(40),SSM23(40),SSM44(40),
     >A(6),B(6),C(6)

      COMMON/TOLERANCE/TOLP1,TOLP2,TOLP3,TOLV1,TOLV2,TOLV3,TOLV4

      COMMON/WORDS/FIB,MATE,MATP,MATV,TCHARP,TCHARV,COMP,ECHAR,LCHAR

      CHARACTER CHAR1*1


      OPEN(8,STATUS='SCRATCH',FORM='UNFORMATTED')

C
C * * DEFAULTS * *
C
      NA = 3
      NUMPLY=2
      ZPOS(1)=-.5
      ZPOS(2)=0.
      ZPOS(3)=0.5
      ANGLE(1)=0.
      ANGLE(2)=90.
      FIB = 'N'
      MATE = 'N'
      MATP = 'N'
      MATV = 'N'
      TCHARP = 'N'
      TCHARV = 'N'
      YSPTS(1) = 0.
      HPRAMPTS(1) = 0.
      TEMPROPF(1) = 21.
      TEMPROPM(1) = 21.
      HD=0.
      NUMCYC = 1
      ECHAR = 'N'
      LCHAR = 'N'
      COMP = 'NO NAME'
      TOLP1=.05
      TOLP2=.005
```

```
      TOLP3=1.0
      TOLV1= 200.
      TOLV2= 15.0
      TOLV3=.001
      TOLV4=50.

 10   WRITE(6,*)
      WRITE(6,*)
      WRITE(6,*)
      WRITE(6,*)
      WRITE(6,*)
      WRITE(6,*)
      WRITE(6,*)
      WRITE(6,*)
      WRITE(6,*) '   * * * * * * * * * * * * * * * * * * * * * * * * * * '
      WRITE(6,*) '   *              LISOL MAIN MENU                    * '
      WRITE(6,*) '   * * * * * * * * * * * * * * * * * * * * * * * * * * '
      WRITE(6,*)
      WRITE(6,*)
      WRITE(6,*) '            (1)  Type of Model  '
      WRITE(6,*)
      WRITE(6,*) '            (2)  Constituent Properties  '
      WRITE(6,*)
      WRITE(6,*) '            (3)  Loading  '
      WRITE(6,*)
      WRITE(6,*) '            (4)  Solve for Response to Applied Loading'
      WRITE(6,*)
      WRITE(6,*) '            (5)  Examine Results '
      WRITE(6,*)
      WRITE(6,*) '            (6)  Quit   '
      WRITE(6,*)
      WRITE(6,*)
      WRITE(6,*) '   Select a submenu (1 to 7): '

      READ(5,*) NF

      IF(NF.EQ.1) THEN

        CALL MODEL


      ELSE IF(NF.EQ.2) THEN

        CALL PROP


      ELSE IF(NF.EQ.3) THEN

        CALL LOAD


      ELSE IF(NF.EQ.4) THEN

        IF(FIB.EQ.'N'.OR.MATE.EQ.'N'.OR.
```

```
     >  (TCHARP.EQ.'N'.AND.TCHARV.EQ.'N')) THEN
          WRITE(6,100)
100   FORMAT(' Constituent properties and loading must first be ',
     >'specified.')
            READ(5,*)
            GO TO 10
      END IF

          REWIND 8

      LCHAR = 'Y'

      IF(NA.EQ.2) THEN


          WRITE(6,*)
      WRITE(6,*)
      WRITE(6,*)
      WRITE(6,*) '  Set New Convergence Tolerances (y/n)'
      WRITE(6,*)
      READ(5,*) CHAR1

          PERTOL1 = TOLP1*100.
          PERTOL2 = TOLP2*100.

      IF(CHAR1.EQ.'y'.OR.CHAR1.EQ.'Y') THEN
 1        WRITE(6,*)
          WRITE(6,1000) PERTOL1,PERTOL2,TOLP3
1000  FORMAT(' (1) Percent load past yield before incrementing = ',
     >F5.2,/,' (2) Percent yield surface convergence tolerance = ',
     >F5.2,/,' (3) Instability convergence factor = ',F5.2,/,
     >' (4) Solve',//,'Enter selection:')
            READ(5,*) NTOL
            IF(NTOL.EQ.1) THEN
            WRITE(6,*)' Enter new incrementing parameter:'
            READ(5,*) PERTOL1
            GO TO 1
          ELSEIF(NTOL.EQ.2) THEN
            WRITE(6,*)' Enter new yield surface thickness:'
            READ(5,*) PERTOL2
            GO TO 1
          ELSEIF(NTOL.EQ.3) THEN
            WRITE(6,*)' Enter new convergence factor:'
            READ(5,*) TOLP3
            GO TO 1
          ELSEIF(NTOL.NE.4) THEN
            GO TO 1
          END IF

          TOLP1=PERTOL1/100.
          TOLP2=PERTOL2/100.
      END IF

      ELSEIF(NA.EQ.3) THEN
```

```
        WRITE(6,*)
      WRITE(6,*)
      WRITE(6,*)
      WRITE(6,*) '  Set New Convergence Tolerances (y/n)'
      WRITE(6,*)
      READ(5,*) CHAR1


      IF(CHAR1.EQ.'y'.OR.CHAR1.EQ.'Y') THEN
 2        WRITE(6,*)
        WRITE(6,2000) TOLV1,TOLV2,TOLV3,TOLV4
2000 FORMAT(' (1) Multiple of elastic rates before incrementing = ',
    >F6.1,/,' (2) Instability convergence factor = ',
    >F5.2,/,' (3) Convergence error tolerance = ',F7.5,/,
    >' (4) Amount above interface failure before incrementing = ',
    >F5.0,/,
    >' (5) Solve',/,' (6) Return to main menu',//,'Enter selection:')
          READ(5,*) NTOL
          IF(NTOL.EQ.1) THEN
          WRITE(6,*)' Enter new incrementing parameter:'
          READ(5,*) TOLV1
          GO TO 2
        ELSEIF(NTOL.EQ.2) THEN
          WRITE(6,*)' Enter new factor (increase for more stability):'
          READ(5,*) TOLV2
          GO TO 2
        ELSEIF(NTOL.EQ.3) THEN
          WRITE(6,*)' Enter new error tolerance:'
          READ(5,*) TOLV3
          GO TO 2
        ELSEIF(NTOL.EQ.4) THEN
          WRITE(6,*)' Enter new interface failure increment:'
          READ(5,*) TOLV4
          GO TO 2
        ELSEIF(NTOL.EQ.6) THEN
          GO TO 10
        ELSEIF(NTOL.NE.5) THEN
          GO TO 2
        END IF

      END IF



      END IF

          CALL SOLV

      ENDFILE 8


      ELSE IF(NF.EQ.5) THEN

        CALL RESULT
```

```
      ELSE IF(NF.EQ.6) THEN

        CLOSE(8)
        STOP

      END IF

        GO TO 10

      END

C   * * * * * * * * * * * *  * * * * * * * * * * * * * *
C
C  BIGPMAT enters the matrix P for the LISOL model.
C
C * * * * * * * * * * * * * * * * * * * *** * * * * * * * * * *

      SUBROUTINE BIGPMAT

      COMMON/TYPEMOD/NA,NUMPLY,ZPOS(7),ANGLE(6)

      COMMON/ELASTPROP/SSF11(40),SSF22(40),SSF12(40),SSF23(40),
     >SSF44(40),SSM11(40),SSM22(40),SSM12(40),SSM23(40),SSM44(40),
     >A(6),B(6),C(6)

      COMMON/VISCOPLAST/H(50,50),HINV(50,50),T(6,3,3),TINT(6,3,3),
     >TH(50,20),BIGP(50,50),N,NCYC,TEM0,TIM0,PZI(6,3),LVEC0(50),
     >EPSMP0(6,3,4),SM0(6,3,4),UIF0(6,2,2),SI0(6,2,2),UI0(6,2,2),
     >K2(6,3),BETA0(6,3,4),OMEG0(6,3,4),EPSTHM1,EPSTHM2,EPSTHF1,
     >EPSTHF2,NDUMP

      COMMON/PMATRIX/PP(6,8,12),S11F,S12F,S22F,S23F,S44F,S11M,S12M,
     >S22M,S23M,S44M,SSI(6,2),SSIT(6,2)

      REAL LVEC0(50),K2(6,3)

       R1=S11M/S12M

      DO I=1,NUMPLY

        T1=A(I)+B(I)
      T2=A(I)+C(I)
      T3=B(I)/A(I)
      T4=C(I)/A(I)

        AA=(1+T4)*(S44F+SSIT(I,1))
      BB=S44M+T4*(S44F+SSIT(I,1))
      I8=8*I
      I5=5*I

        DO J=1,3
          BIGP(I8-7,J)=TINT(I,1,J)
```

```
   BIGP(I8-6,J)=-T1*TINT(I,2,J)
   BIGP(I8-5,J)=0.
   BIGP(I8-4,J)=0.
   BIGP(I8-3,J)=0.
   BIGP(I8-2,J)=0.
   BIGP(I8-1,J)=0.
   BIGP(I8,J)=T1/(S44M*(A(I)*AA/BB+B(I)))*TINT(I,3,J)
 END DO

 DO J=4,6
   BIGP(I8-7,J)=-TH(I8-7,J)
   BIGP(I8-6,J)=-TH(I8-6,J)
   BIGP(I8-5,J)=-TH(I8-5,J)
   BIGP(I8-4,J)=-TH(I8-4,J)
   BIGP(I8-3,J)=-TH(I8-3,J)
   BIGP(I8-2,J)=-TH(I8-2,J)
   BIGP(I8-1,J)=-TH(I8-1,J)
   BIGP(I8,J)=-TH(I8,J)
 END DO

 BIGP(I8-7,I5+2)=-S11F
 BIGP(I8-7,I5+3)=-S12F
 BIGP(I8-7,I5+4)=0.
 BIGP(I8-7,I5+5)=T3*S12F
 BIGP(I8-7,I5+6)=0.

 BIGP(I8-6,I5+2)=A(I)*S12F
 BIGP(I8-6,I5+3)=A(I)*S22F+B(I)*S22M+A(I)*SSI(I,1)
 BIGP(I8-6,I5+4)=B(I)*S12M
 BIGP(I8-6,I5+5)=B(I)*(S23M-S23F)
 BIGP(I8-6,I5+6)=0.

 BIGP(I8-5,I5+2)=S11F
 BIGP(I8-5,I5+3)=S12F-S12M
 BIGP(I8-5,I5+4)=-S11M
 BIGP(I8-5,I5+5)=-S12M-T3*S12F
 BIGP(I8-5,I5+6)=0.

 BIGP(I8-4,I5+2)=A(I)*S12F
 BIGP(I8-4,I5+3)=A(I)*(S22F-S22M+SSI(I,1))
 BIGP(I8-4,I5+4)=B(I)*S12M-R1*S22M*T1
 BIGP(I8-4,I5+5)=-T1*S12M/R1+B(I)*(S23M-S23F)
 BIGP(I8-4,I5+6)=-T1*(S12M-R1*S22M)

 BIGP(I8-3,I5+2)=A(I)*S12F
 BIGP(I8-3,I5+3)=A(I)*(S23F-S23M)
 BIGP(I8-3,I5+4)=-A(I)*S12M
 BIGP(I8-3,I5+5)=C(I)*(1+T3)*S12M/R1-B(I)*S22F-(T2+T3*C(I))
>                  *S22M-B(I)*SSI(I,2)
 BIGP(I8-3,I5+6)=0.

 BIGP(I8-2,I5+2)=A(I)**2./(T1*T2)
 BIGP(I8-2,I5+3)=0.
 BIGP(I8-2,I5+4)=A(I)*B(I)/(T1*T2)
```

```
      BIGP(I8-2,I5+5)=C(I)/(T2*R1)
      BIGP(I8-2,I5+6)=C(I)/T2

      BIGP(I8-1,I5+2)=0.
      BIGP(I8-1,I5+3)=1.
      BIGP(I8-1,I5+4)=C(I)*R1/T2
      BIGP(I8-1,I5+5)=0.
      BIGP(I8-1,I5+6)=-C(I)*R1/T2

      BIGP(I8,I5+2)=0.
      BIGP(I8,I5+3)=0.
      BIGP(I8,I5+4)=0.
      BIGP(I8,I5+5)=0.
      BIGP(I8,I5+6)=0.

      END DO

      RETURN

      END
C   * * * * * * * * * * * * *  * * * * * * * * * * * * * *
C
C  BIGPPMAT enters the matrix Pplast for each ply
C
C * * * * * * * * * * * * * * * * * * * *** * * * * * * * * * *

      SUBROUTINE BIGPPMAT

      COMMON/TYPEMOD/NA,NUMPLY,ZPOS(7),ANGLE(6)

      COMMON/ELASTPROP/SSF11(40),SSF22(40),SSF12(40),SSF23(40),
     >SSF44(40),SSM11(40),SSM22(40),SSM12(40),SSM23(40),SSM44(40),
     >A(6),B(6),C(6)

      COMMON/PMATRIX/PP(6,8,12),S11F,S12F,S22F,S23F,S44F,S11M,S12M,
     >S22M,S23M,S44M,SSI(6,2),SSIT(6,2)


      R1=S12M/S11M
      DO I=1,NUMPLY

      T4=C(I)/A(I)

        AA=(1+T4)*(S44F+SSIT(I,1))
      BB=S44M+T4*(S44F+SSIT(I,1))

        DO J=1,12
          PP(I,1,J)=0.
      END DO
      DO J=1,4
        PP(I,2,J)=0.
      END DO
      PP(I,2,5)=B(I)
```

```
DO J=6,12
  PP(I,2,J)=0.
END DO
DO J=3,7
  DO K=1,3
    PP(I,J,K)=0.
  END DO
END DO
DENOM=S44M*(A(I)*AA/BB+B(I))
PP(I,8,1)=-B(I)/(DENOM*(1+C(I)/A(I)))
PP(I,8,2)=-B(I)*C(I)/(DENOM*(A(I)+C(I)))
PP(I,8,3)=-A(I)*(1-S44M/BB)/DENOM
DO J=4,12
  PP(I,8,J)=0.
END DO

PP(I,3,4)=-1.
DO J=5,12
  PP(I,3,J)=0.
END DO

APB=A(I)+B(I)
APC=A(I)+C(I)

PP(I,4,4)=-APB*S22M/S12M
PP(I,4,5)=B(I)
PP(I,4,6)=0.
PP(I,4,7)=-A(I)*R1+APB*S22M/S12M
PP(I,4,8)=-B(I)
PP(I,4,9)=0.
PP(I,4,10)=A(I)*R1
PP(I,4,11)=-A(I)
PP(I,4,12)=0.

PP(I,5,4)=0.
PP(I,5,5)=0.
PP(I,5,6)=-A(I)
PP(I,5,7)=C(I)*R1
PP(I,5,8)=0.
PP(I,5,9)=-C(I)
PP(I,5,10)=-C(I)*R1
PP(I,5,11)=0.
PP(I,5,12)=C(I)

PP(I,6,4)=0.
PP(I,6,5)=0.
PP(I,6,6)=0.
PP(I,6,7)=A(I)*C(I)/(APB*APC*S11M)
PP(I,6,8)=0.
PP(I,6,9)=0.
PP(I,6,10)=-PP(I,6,7)
PP(I,6,11)=0.
PP(I,6,12)=0.
```

```
      PP(I,7,4)=C(I)/(APC*S12M)
      PP(I,7,5)=0.
      PP(I,7,6)=0.
      PP(I,7,7)=-PP(I,7,4)
      PP(I,7,8)=0.
      PP(I,7,9)=0.
      PP(I,7,10)=0.
      PP(I,7,11)=0.
      PP(I,7,12)=0.

      END DO
      RETURN

      END

C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C     The subroutine BODDIR calculates the inelastic strain rate using
C   the Bodner-Partom model with directional hardening.
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C

      SUBROUTINE BODDIR(Z0D1,BND1,BM1D1,Z1D1,R1D1,A1D1,BM2D1,Z2D1,R2D1,
     >A2D1,Z3D1,DZ1DT,DZ2DT,DZ3DT,DNOT,TDOT,DTIM,SMP,SM,RT,EPSEFFDP,
     >BETA,BETA0,ZI,ZI0,EPSCALDP)


      COMMON/TYPEMOD/NA,NUMPLY,ZPOS(7),ANGLE(6)

      REAL  EPSEFFDP(6,3),SMP(6,3,4),RT(6,3),EPSCALDP(6,3),K2(6,3),
     >SM(6,3,4),BETA(6,3,4),BETA0(6,3,4),ZI(6,3),ZI0(6,3),
     >EPSMPD(6,3,4),WPD(6,3),U(6,3,4),DZI(6,3),DBETA(6,3,4)


      DO I=1,NUMPLY

        DO J=1,3

        K2(I,J)=0.5*(SMP(I,J,1)**2+SMP(I,J,2)**2+SMP(I,J,3)**2+
     >          2.*SMP(I,J,4)**2)
        RT(I,J)=SQRT(3.*K2(I,J))
      DENOM = SQRT(SM(I,J,1)**2+SM(I,J,2)**2+SM(I,J,3)**2+
     >            2.*SM(I,J,4)**2)
        IF(RT(I,J).LT.5.) THEN
        EPSCALDP(I,J)=0.0
      ELSE
        DO K=1,4
          U(I,J,K)=SM(I,J,K)/DENOM
            EPSMPD(I,J,K) = 1.5*EPSEFFDP(I,J)*SMP(I,J,K)/RT(I,J)
        END DO
```

```
         EPSMPD(I,J,4)=2.*EPSMPD(I,J,4)
         WPD(I,J)=SM(I,J,1)*EPSMPD(I,J,1)+SM(I,J,2)*EPSMPD(I,J,2)
     >              +SM(I,J,3)*EPSMPD(I,J,3)+SM(I,J,4)*EPSMPD(I,J,4)
           Q=-BM1D1*WPD(I,J)-A1D1*Z1D1**(1.-R1D1)*(ZI(I,J)-Z2D1)**R1D1
     >        /ZI(I,J)+(DZ1DT-DZ2DT)/(Z1D1-Z2D1)*TDOT
           DZI(I,J)=(BM1D1*Z1D1*WPD(I,J)+(-Z2D1*DZ1DT+Z1D1*DZ2DT)*TDOT/
     >       (Z1D1-Z2D1)+ZI0(I,J)*Q)/(1/DTIM-Q)
           DUM=SQRT(BETA(I,J,1)**2+BETA(I,J,2)**2+BETA(I,J,3)**2+2.*
     >        BETA(I,J,4)**2.)
           Q2 = -BM2D1*WPD(I,J)-A2D1*(DUM/Z1D1)**(R2D1-1.)+DZ3DT*
     >          TDOT/Z3D1
         DO K=1,4
           DBETA(I,J,K)=(BM2D1*Z3D1*WPD(I,J)*U(I,J,K)+BETA0(I,J,K)*
     >                    Q2)/(1./DTIM - Q2)
             BETA(I,J,K)=BETA0(I,J,K)+DBETA(I,J,K)
         END DO
         ZI(I,J)=ZI0(I,J)+DZI(I,J)
         IF(ZI(I,J).LT.Z2D1) THEN
           ZI(I,J)=Z2D1
         ELSEIF(ZI(I,J).GT.Z1D1) THEN
           ZI(I,J)=Z1D1
         END IF
         ZD = BETA(I,J,1)*U(I,J,1)+BETA(I,J,2)*U(I,J,2)+BETA(I,J,3)*
     >        U(I,J,3)+2.*BETA(I,J,4)*U(I,J,4)
           EPSCALDP(I,J) = 2./SQRT(3.)*DNOT*EXP(-0.5*((ZI(I,J)+ZD)/
     >        RT(I,J))**(2*BND1))
         END IF

       END DO

       END DO

       RETURN

       END
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C    The subroutine BODISO calculates the inelastic strain rate using
C  the original Bodner-Partom model with isotropic hardening only.
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C

       SUBROUTINE BODISO(Z0A1,PNA1,PMA1,Z1A1,DNOT,DTIM,SMP,SM,RT,
      >ZI,ZI0,EPSEFFDP,EPSCALDP)

       COMMON/TYPEMOD/NA,NUMPLY,ZPOS(7),ANGLE(6)

       REAL  EPSEFFDP(6,3),SMP(6,3,4),RT(6,3),
      >EPSCALDP(6,3),K2(6,3),SM(6,3,4),ZI(6,3),ZI0(6,3),
```

```
     >EPSMPD(6,3,4),WPD(6,3)


      DO I=1,NUMPLY
        DO J=1,3
          K2(I,J)=0.5*(SMP(I,J,1)**2+SMP(I,J,2)**2+SMP(I,J,3)**2+
     >          2.*SMP(I,J,4)**2)
          RT(I,J)=SQRT(3.*K2(I,J))
          IF(RT(I,J).LT.5.) THEN
          EPSCALDP(I,J)=0.0
        ELSE
          DO K=1,4
              EPSMPD(I,J,K) = 1.5*EPSEFFDP(I,J)*SMP(I,J,K)/RT(I,J)
          END DO
          EPSMPD(I,J,4)=2.*EPSMPD(I,J,4)
          WPD(I,J)=SM(I,J,1)*EPSMPD(I,J,1)+SM(I,J,2)*EPSMPD(I,J,2)
     >      +SM(I,J,3)*EPSMPD(I,J,3)+SM(I,J,4)*EPSMPD(I,J,4)
            Q=PMA1*WPD(I,J)/Z0A1
          DZI=Q*(Z1A1-ZI0(I,J))/(1/DTIM+Q)
          ZI(I,J)=ZI0(I,J)+DZI
          IF(ZI(I,J).LT.Z0A1) THEN
            ZI(I,J)=Z0A11
          ELSEIF(ZI(I,J).GT.Z1A1) THEN
            ZI(I,J)=Z1A1
          END IF
          POW = -0.5*(PNA1+1)/PNA1*(ZI(I,J)/RT(I,J))**(2*PNA1)
            EPSCALDP(I,J) = 2./SQRT(3.)*DNOT*EXP(POW)
          END IF
      END DO
      END DO

      RETURN

      END
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C  GAUSS performs Gauss elimination to produce the solution to
C  a matrix-vector equation.
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *


      SUBROUTINE GAUSS(N,MAT,FVEC,XVEC)

      REAL MAT(50,50),FVEC(50),XVEC(50),AMAT(50,51),SMAT(50,51)

C
C  Create the augmented matrix consisting of an N X (N+1) matrix
C  where MAT is the NxN portion and FVEC is the final column.
C
      DO I=1,N
        DO J=1,N
        AMAT(I,J)=MAT(I,J)
      END DO
```

```
          AMAT(I,N+1)=FVEC(I)
        END DO
C
C  Begin Gauss elimination
C
        DO K=1,N-1
C
C  First find the maximum coefficient in column K whose row is
C  greater than or equal to K.
C
        DUM=0.

          DO I=K,N
          IF(ABS(AMAT(I,K)).GT.ABS(DUM)) THEN
            J=I
            DUM=AMAT(I,K)
          END IF
        END DO
        IF(DUM.EQ.0.) THEN
          WRITE(6,*)
          WRITE(6,*)
          WRITE(6,*)
          WRITE(6,*) '       Matrix has no inverse !'
          WRITE(6,*)
          WRITE(6,*) ' Attempted to invert a singular matrix'
          WRITE(6,*) ' in subroutine GAUSS.'
          WRITE(6,*)
          READ(5,*)
          STOP
        END IF

C
C     Exchange rows K & J.
C
          IF(J.NE.K) THEN
            DO L=1,N+1
            SMAT(J,L) = AMAT(J,L)
            AMAT(J,L) = AMAT(K,L)
            AMAT(K,L) = SMAT(J,L)
          END DO
        END IF

C
C     Perform Gauss elimination
C
          DO J=K+1,N

          AMULT=AMAT(J,K)/AMAT(K,K)
```

```
          DO I=K+1,N+1

            AMAT(J,I)=AMAT(J,I)-AMULT*AMAT(K,I)

          END DO

        END DO


        END DO
C
C  Start back substitution
C
      IF(AMAT(N,N).EQ.0.) THEN
            WRITE(6,*)
      WRITE(6,*)
      WRITE(6,*)
      WRITE(6,*) '      Matrix has no inverse !'
      WRITE(6,*)
      WRITE(6,*) ' Attempted to invert a singular matrix'
      WRITE(6,*) ' in subroutine GAUSS.'
      WRITE(6,*)
      READ(5,*)
      STOP
      END IF

      XVEC(N)=AMAT(N,N+1)/AMAT(N,N)

      DO K=1,N-1
        I=N-K
        DUM=0.
      DO ISUM=I+1,N
        DUM=DUM+AMAT(I,ISUM)*XVEC(ISUM)
      END DO
      XVEC(I)=(AMAT(I,N+1)-DUM)/AMAT(I,I)
      END DO

      RETURN

      END
C * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C   I N V E R S E
C
C * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C     The subroutine INVERSE calculates the inverse of a square
C   matrix, A, of size N and returns it as AINV.  Gauss-Jordan
elimination
C   is used in the calculations.  Arguments include the matrix size (N),
C   the matrix (A), and the inverse matrix (AINV).
```

```
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * *
      SUBROUTINE INVERSE(N,A,AINV)

      REAL A(50,50),AINV(50,50),AI(50,100),S(50,100)
      INTEGER N,I,J,K,M

C
C      Create the augmented matrix, AI, which is an N x 2N matrix
C   containing the matrix A in the first N columns and the identity
C   matrix in columns N+1 to 2N.
C

      DO J = 1, N
        DO I = 1, N
        AI(I,J) = A(I,J)
        AI(I,J+N) = 0.
      END DO
      END DO

      DO I = 1,N
        AI(I,I+N) = 1.
      END DO


C
C  *  *   Begin Gauss-Jordan elimination.  *  *
C

      DO J=1,N

C
C    First find a row in column J with a nonzero coefficient.
C
        DUM=0.

        DO I=J,N
        IF(ABS(AI(I,J)).GT.ABS(DUM)) THEN
          K=I
          DUM=AI(I,J)
        END IF
      END DO
      IF(DUM.EQ.0.) THEN
        WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*) '      Matrix has no inverse !'
        WRITE(6,*)
        WRITE(6,*) ' Attempted to invert a singular matrix'
        WRITE(6,*) ' in subroutine INVERSE.'
        WRITE(6,*)
        READ(5,*)
        STOP
```

```
      END IF

C
C     Exchange rows J & K.
C

        IF(K.NE.J) THEN
        DO L = 1,2*N
          S(K,L) = AI(K,L)
          AI(K,L) = AI(J,L)
          AI(J,L) = S(K,L)
        END DO
      END IF

C
C     Perform Gauss-Jordan elimination of each column, J.
C

        DO I=1,N
        IF(I.NE.J) THEN
          AMULT = AI(I,J)/AI(J,J)
          DO M=J+1,2*N
            AI(I,M) = AI(I,M) - AMULT*AI(J,M)
          END DO
        END IF
      END DO
C
C   Must operate on pivoted row last
C
        DO M=J+1,2*N
        AI(J,M) = AI(J,M)/AI(J,J)
      END DO


      END DO

C
C     Create AINV from the new augmented matrix
C

      DO I=1,N
        DO J=1,N
        AINV(I,J) = AI(I,J+N)
      END DO
      END DO


      RETURN

      END
C
C  * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C  *                                                     *
```

```
C  *                   A P P L I E D                         *
C  *                   L O A D I N G                         *
C  *                                                         *
C  * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C    The LOAD subroutine sets the applied loading to be
C  used with the program FTS.
C
C  * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C


      SUBROUTINE LOAD

      CHARACTER CHAR1*1, CYCSYM(999)*1, INLOD*15, OUTLOD*15

      CHARACTER FIB*1,MATE*1,MATP*1,MATV*1,TCHARP*1,TCHARV*1,
     >COMP*40, ECHAR*1,LCHAR*1

      COMMON/TYPEMOD/NA,NUMPLY,ZPOS(7),ANGLE(6)

      COMMON/LOADING/NC1,NC2,NUMP,NUMCYC,DT(9999),TEMP(9999),NX(9999),
     >NY(9999),NXY(9999),M(9999)

      COMMON/WORDS/FIB,MATE,MATP,MATV,TCHARP,TCHARV,COMP,ECHAR,LCHAR

      REAL NX(9999),NY(9999),NXY(9999)


 3          WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
            WRITE(6,*) '   * * * * * * * * * * * * * * * * * '
            WRITE(6,*) '   *   Applied Loading Menu      * '
            WRITE(6,*) '   * * * * * * * * * * * * * * * * * '
            WRITE(6,*)
            WRITE(6,*)
            WRITE(6,*) '     (1) Read input file '
            WRITE(6,*) '     (2) Save existing load sequence to a file '
            WRITE(6,*) '     (3) Composite load history '
            WRITE(6,*) '     (4) Return to main menu '
      WRITE(6,*)
      WRITE(6,*)
      WRITE(6,*) '  Enter Selection:  '
        READ(5,*) NL

      IF(NL.EQ.1) THEN
```

```
      WRITE(6,*)
      WRITE(6,*)' Enter the name of the load file you wish to read.'
      READ(5,2001) INLOD
      OPEN(UNIT=20,FILE=INLOD,STATUS='OLD')
      READ(20,2003) TCHARP,TCHARV,NUMP,NC1,NC2,NUMCYC
2003 FORMAT(2A2,4I7)
      DO I=1,NUMP
        READ(20,*) DT(I),TEMP(I),NX(I),NY(I),NXY(I),M(I)
      END DO
      CLOSE(UNIT=20)
      GO TO 3

    ELSE IF(NL.EQ.2) THEN

      IF(TCHARP.EQ.'N'.AND.TCHARV.EQ.'N') THEN
        WRITE(6,1032)
1032 FORMAT(' No load history has yet been entered.  Please return to',
   >' the Applied ',/,' Loading menu by pressing <return>.')
          READ(5,*)
        GO TO 3
      END IF

      WRITE(6,*)
      WRITE(6,*)' Enter the name of the load file you wish to save.'
      READ(5,2001) OUTLOD
2001 FORMAT(A15)
      OPEN(UNIT=21,FILE=OUTLOD,STATUS='NEW')
      WRITE(21,2003) TCHARP,TCHARV,NUMP,NC1,NC2,NUMCYC
      DO I=1,NUMP
        WRITE(21,*) DT(I),TEMP(I),NX(I),NY(I),NXY(I),M(I)
      END DO
      CLOSE(UNIT=21)
      GO TO 3

    ELSE IF(NL.EQ.3) THEN

      IF(NA.LE.2) THEN


      ELSE

 14     DO I=1,NUMP
          CYCSYM(I) = ' '
          IF(I.EQ.NC1.OR.I.EQ.NC2) CYCSYM(I) = '*'
        END DO

        WRITE(6,1035)
1035 FORMAT(////,'      dt (s)   T (deg C)   NX (MPa-mm)   NY (MPa-mm)',
   >'   NXY (MPa-mm) #Incr',/)

        DO I=1,NUMP
         WRITE(6,1036) CYCSYM(I),I,DT(I),TEMP(I),NX(I),NY(I),
   >       NXY(I),M(I)
```

```
1036 FORMAT(A1,'(',I2,')', 2F9.2, 3F11.2,I4)
            IF(I.GT.100) THEN
            WRITE(6,*) ' ******>'
            GO TO 101
          END IF
        END DO

 101       WRITE(6,1027) NUMP+1,NUMP+2,NUMP+3,NUMCYC,NUMP+4
           READ(5,*) NLP
        NUMPAD = 0
1027 FORMAT(' (',I2,')  Add points',/,
    >' (',I2,')  Define a repeating cycle (points from * to * are ',
    >'repeated N times)',/,
    >' (',I2,')  Change number of cycles (present no. = ',I7,')',/,
    >' (',I2,')  Save and return to Applied Load menu',//,
    >'  Point to modify/delete or other selection:')


        DO I=1,NUMP

          IF(NLP.EQ.I) THEN
            WRITE(6,*)
            WRITE(6,*)' Delete or Modify point',I,' ? (d/m)'
            READ(5,*) CHAR1
            IF(CHAR1.EQ.'d') THEN
              DO N=I,NUMP
              DT(N) = DT(N+1)
              TEMP(N) = TEMP(N+1)
              NX(N) = NX(N+1)
              NY(N) = NY(N+1)
              NXY(N) = NXY(N+1)
              M(N) = M(N+1)
            END DO
            NUMPAD = -1
            ELSE IF(CHAR1.EQ.'m') THEN
              WRITE(6,1028) I
1028 FORMAT(/,' Enter the applied loading for point ',I2)

              WRITE(6,1039)
1039 FORMAT('    dt (s)   T (deg C)    NX (MPa-mm)   NY (MPa-mm)',
    >'  NXY (MPa-mm) #Incr')
                READ(5,*) DT(I),TEMP(I),NX(I),NY(I),NXY(I),M(I)
            END IF
          END IF

        END DO

        IF(NLP.EQ.NUMP+1) THEN
          WRITE(6,*)
          WRITE(6,*)' Enter the number of points to add.'
          READ(5,*) NUMPAD
          WRITE(6,*)
          WRITE(6,*)' Enter load for ',NUMPAD,' additional points.'
          WRITE(6,1039)
```

```
          DO I=NUMP+1,NUMP+NUMPAD
                READ(5,*) DT(I),TEMP(I),NX(I),NY(I),NXY(I),M(I)
          END DO
          TCHARV='Y'
        END IF

        IF(NLP.EQ.NUMP+2) THEN
          WRITE(6,1030)
 1030 FORMAT(/,' Enter the load point that begins the repeating cycle.')

            READ(5,*) NC1
          WRITE(6,1031)
 1031 FORMAT(/,' Enter the load point that ends the repeating cycle.')
            READ(5,*) NC2
        END IF

        IF(NLP.EQ.NUMP+3) THEN
          WRITE(6,*)
          WRITE(6,*)' Enter the number of desired cycles.'
          READ(5,*) NUMCYC
        END IF

        IF(NLP.EQ.NUMP+4) THEN
          GO TO 3
        END IF

        NUMP=NUMP+NUMPAD
        GO TO 14

       END IF

      ELSE IF(NL.NE.4) THEN
       GO TO 3

      END IF

        RETURN

      END
C
C  * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C  *                                                     *
C  *                     M O D E L                       *
C  *                                                     *
C  * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C    The MODEL subroutine sets the type of analysis model to be
C  used with the program LISOL.
C
C  * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      SUBROUTINE MODEL

      CHARACTER CHAR1*1
```

```
      COMMON/TYPEMOD/NA,NUMPLY,ZPOS(7),ANGLE(6)

      REAL THICK(6)

  1         WRITE(6,*)
            WRITE(6,*)
            WRITE(6,*) '   * * * * * * * * * * * * * * * * '
            WRITE(6,*) '   *        Type of Model        * '
            WRITE(6,*) '   * * * * * * * * * * * * * * * * '
            WRITE(6,*)
            WRITE(6,*)
            WRITE(6,*) ' * Type of analysis * '
            WRITE(6,*)
            WRITE(6,*) '      **N/A** (1) Linear Elastic  '
            WRITE(6,*) '      **N/A** (2) Elastic-Plastic '
            WRITE(6,*) '       (3) Visco-plastic '
            WRITE(6,*)
            WRITE(6,*) ' Present analysis selection: ',NA
            WRITE(6,*)
            WRITE(6,*) ' Number of plies = ',NUMPLY
            WRITE(6,*)
      WRITE(6,*) ' Ply thickness (mm)       Ply angle'


      DO I=1,NUMPLY
          THICK(I) = ZPOS(I+1)-ZPOS(I)
        WRITE(6,1000)  THICK(I), ANGLE(I)
1000  FORMAT(5X,2F15.4)
      END DO
            WRITE(6,*)
            WRITE(6,*) '      Change above selections (y/n) ?  '
      READ(5,*) CHAR1

      IF(CHAR1.EQ.'y'.OR.CHAR1.EQ.'Y') THEN

        WRITE(6,*)
        WRITE(6,*) ' Enter new analysis type (#,#):'
        READ(5,*) NA
        WRITE(6,*)
        WRITE(6,*) ' Enter number of plies:'
        READ(5,*) NUMPLY
        WRITE(6,*)
        WRITE(6,*) ' Enter thickness and angle for each ply '
        DO I=1,NUMPLY
          WRITE(6,*) ' thickness and angle for ply ',I
          READ(5,*) THICK(I),ANGLE(I)
        END DO
          TOT = 0.0
          DO I=1,NUMPLY
            TOT = TOT + THICK(I)
          END DO
        ZPOS(1)=-TOT/2.
          DO I=1,NUMPLY
```

```
            ZPOS(I+1)=ZPOS(I)+THICK(I)
          END DO
        WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
        GO TO 1


      ELSE IF(CHAR1.NE.'n') THEN
        GO TO 1

      END IF

        RETURN

      END
C
C  * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C  *                                                       *
C  *               C O N S T I T U E N T                   *
C  *                P R O P E R T I E S                    *
C  *                                                       *
C  * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C
C    The PROP subroutine sets the constituent properties
C  for the program LISOL.
C
C
C  * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C

      SUBROUTINE PROP

      REAL NUF12(40), NUF23(40), NUM12(40), NUM23(40)

      CHARACTER FIB*1,MATE*1,MATP*1,MATV*1,TCHARP*1,TCHARV*1,
     >COMP*40, ECHAR*1,LCHAR*1

      CHARACTER CHAR1*1,INPROP*15,OUTPROP*15

      COMMON/TYPEMOD/NA,NUMPLY,ZPOS(7),ANGLE(6)

      COMMON/MATERIAL/NUF12(40),NUF23(40),NUM12(40),NUM23(40),GM12(40),
     >EM22(40),EM11(40),AR,VF,GF12(40),EF22(40),EF11(40),HPRAMPTS(40),
     >YSPTS(40),TEMPROPF(40),TEMPROPM(40),NTEMF,NTEMM,HD,ALPHAF1(40),
     >ALPHAF2(40),ALPHAM1(40),ALPHAM2(40),OSAT(40),F1(40),F3(40),Z0(40),
     >BN(40),DNOT,Z0D(40),BND(40),BM1D(40),Z1D(40),R1D(40),
     >A1D(40),BM2D(40),Z2D(40),R2D(40),A2D(40),Z3D(40),TEMPREF,NTEMI,
     >SIC,TEMPROPI(40),SIFN1(40),UIFN1OA(40),SIFT1(40),UIFT1OA(40)
```

```
      COMMON/WORDS/FIB,MATE,MATP,MATV,TCHARP,TCHARV,COMP,ECHAR,LCHAR


 2          WRITE(6,*)
       WRITE(6,*)
       WRITE(6,*)
       WRITE(6,*)
       WRITE(6,*)
       WRITE(6,*)
       WRITE(6,*)
       WRITE(6,*)
       WRITE(6,*)
            WRITE(6,*) '    * * * * * * * * * * * * * * * * * '
            WRITE(6,*) '    *   Constituent Properties     * '
            WRITE(6,*) '    * * * * * * * * * * * * * * * * * '
            WRITE(6,*)
            WRITE(6,*)
            WRITE(6,*) '      (1) Read input file '
            WRITE(6,*) '      (2) Save existing properties to a file '
      WRITE(6,*) '      (3) Composite Material Name '
            WRITE(6,*) '      (4) Fiber properties '
            WRITE(6,*) '      (5) Matrix properties '
            WRITE(6,*) '      (6) Return to main menu '
      WRITE(6,*)
      WRITE(6,*)
      WRITE(6,*) '  Enter Selection:  '
        READ(5,*) NP


      IF(NP.EQ.1) THEN

        WRITE(6,*)
        WRITE(6,*) ' Enter the name of the input file '
        READ(5,2001) INPROP
2001  FORMAT(A15)
        OPEN(UNIT=10,FILE=INPROP,STATUS='OLD')
        READ(10,2000) COMP
2000  FORMAT(A40)
        READ(10,2002) FIB,MATE,MATP,MATV
2002  FORMAT(4A2)
          READ(10,*)
          READ(10,*) NTEMF,AR,VF
        DO I=1,NTEMF
          READ(10,*) TEMPROPF(I),EF11(I),NUF12(I),EF22(I),NUF23(I),
     >                  GF12(I)
          READ(10,*) ALPHAF1(I),ALPHAF2(I)
            READ(10,*)
        END DO
          READ(10,*)
          READ(10,*) NTEMM,HD,DNOT,TEMPREF
        DO I=1,NTEMM
          READ(10,*) TEMPROPM(I),EM11(I),NUM12(I),EM22(I),NUM23(I),
```

```
    >                  GM12(I)
         READ(10,*) ALPHAM1(I),ALPHAM2(I),HPRAMPTS(I),YSPTS(I)
         READ(10,*) OSAT(I), F1(I),F3(I), Z0(I), BN(I)
         READ(10,*) Z0D(I),BND(I),BM1D(I),Z1D(I),R1D(I),A1D(I)
         READ(10,*) BM2D(I),Z2D(I),R2D(I),A2D(I),Z3D(I)
           READ(10,*)
       END DO
       READ(10,*)
         READ(10,*) NTEMI,SIC
       DO I=1,NTEMI
         READ(10,*) TEMPROPI(I),SIFN1(I),UIFN10A(I)
         READ(10,*) SIFT1(I),UIFT10A(I)
           READ(10,*)
       END DO
       CLOSE(UNIT=10)
       GO TO 2

     ELSE IF(NP.EQ.2) THEN

         IF(COMP.EQ.'NO NAME') THEN
         WRITE(6,1015)
1015 FORMAT(/,' The composite has not yet been named.  Please return',
    >' to the',/,' Constituent Properties menu by pressing <return> or'
    >,' <enter>',/, ' and name the composite. ')
           READ(5,*)
         GO TO 2

         ELSE IF(FIB.EQ.'N') THEN
         WRITE(6,1016)
1016 FORMAT(/,' Fiber properties have not yet been specified.  Please',
    >' return to',/,' the Constituent Properties menu by pressing ',
    >'<return> or <enter>',/, ' and enter the fiber properites. ')
           READ(5,*)
         GO TO 2

         ELSE IF(MATE.EQ.'N') THEN
         WRITE(6,1017)
1017 FORMAT(/,' Matrix properties have not yet been specified.  Please'
    >,'return to',/,' the Constituent Properties menu by pressing ',
    >'<return> or <enter>',/, ' and enter the matrix properites. ')
           READ(5,*)
         GO TO 2
       END IF

       WRITE(6,*)
       WRITE(6,*) ' Enter the name of the file to be saved '
       READ(5,2001) OUTPROP
       OPEN(UNIT=11,FILE=OUTPROP,STATUS='UNKNOWN')
       WRITE(11,2000) COMP
       WRITE(11,2002) FIB,MATE,MATP,MATV
         WRITE(11,*)
         WRITE(11,*) NTEMF,AR,VF
       DO I=1,NTEMF
         WRITE(11,*) TEMPROPF(I),EF11(I),NUF12(I),EF22(I),NUF23(I),
```

```
     >                  GF12(I)
            WRITE(11,*) ALPHAF1(I),ALPHAF2(I)
            WRITE(11,*)
        END DO
        WRITE(11,*)
        WRITE(11,*) NTEMM,HD,DNOT,TEMPREF
        DO I=1,NTEMM
          WRITE(11,*) TEMPROPM(I),EM11(I),NUM12(I),EM22(I),NUM23(I),
     >                  GM12(I)
          WRITE(11,*) ALPHAM1(I),ALPHAM2(I),HPRAMPTS(I),YSPTS(I)
          WRITE(11,*) OSAT(I), F1(I),F3(I), Z0(I), BN(I)
          WRITE(11,*) Z0D(I),BND(I),BM1D(I),Z1D(I),R1D(I),A1D(I)
          WRITE(11,*) BM2D(I),Z2D(I),R2D(I),A2D(I),Z3D(I)
            WRITE(11,*)
        END DO
        WRITE(11,*)
          WRITE(11,*) NTEMI,SIC
        DO I=1,NTEMI
          WRITE(11,*) TEMPROPI(I),SIFN1(I),UIFN10A(I)
          WRITE(11,*) SIFT1(I),UIFT10A(I)
            WRITE(11,*)
        END DO
        CLOSE(UNIT=11)
        GO TO 2

      ELSE IF(NP.EQ.3) THEN
        WRITE(6,*)
        WRITE(6,*)' Composite Description:   ',COMP
        WRITE(6,*)
        WRITE(6,*)' Do you wish to change the description (y/n)?'
        READ(5,*) CHAR1

        IF(CHAR1.EQ.'y') THEN
          WRITE(6,1019)
1019 FORMAT(/,' Enter a description of the composite (40 characters or'
     >,' less) :')
          READ(5,2000) COMP
        END IF
        GO TO 2

      ELSE IF(NP.EQ.4) THEN

          WRITE(6,*)
          WRITE(6,*)
          WRITE(6,*)
          WRITE(6,*)
          WRITE(6,*)
          WRITE(6,*)
          WRITE(6,*)
          WRITE(6,*)'HD = ',HD,'    AR = ',AR,'     VF = ',VF
        WRITE(6,*)'     TEMPREF=',
     >               TEMPREF
        WRITE(6,*)
        WRITE(6,1001)
```

```
       DO I=1,NTEMF
        WRITE(6,1000) TEMPROPF(I),EF11(I),EF22(I),GF12(I),NUF12(I),
    >                  NUF23(I),ALPHAF1(I),ALPHAF2(I)
         END DO
1000   FORMAT(4F11.2,2F11.4,2E11.4)
1001   FORMAT(' TEMP (C)   E11 (GPA)  E22 (GPA)  G12 (GPA)    NU12    ',
    >'     NF23       ALPHA1      ALPHA2')

     ELSE IF(NP.EQ.5) THEN
         WRITE(6,*)
         WRITE(6,*)
         WRITE(6,*)
         WRITE(6,*)
         WRITE(6,*)
         WRITE(6,*)
         WRITE(6,*)
         WRITE(6,*)'DNOT = ', DNOT
       WRITE(6,*)
       WRITE(6,1001)
       DO I=1,NTEMM
        WRITE(6,1000) TEMPROPM(I),EM11(I),EM22(I),GM12(I),NUM12(I),
    >                  NUM23(I),ALPHAM1(I),ALPHAM2(I)
         END DO
       WRITE(6,*)
       WRITE(6,*)
       WRITE(6,*)
       WRITE(6,1002)
1002 FORMAT(' H  Y     OSAT          F1          F3          Z0          ',
    >'N')
       DO I=1,NTEMM
         WRITE(6,1003)HPRAMPTS(I),YSPTS(I),OSAT(I),F1(I),F3(I),Z0(I),
    >      BN(I)
         END DO
       WRITE(6,*)
       WRITE(6,*)
       WRITE(6,*)  '        Directional hardening constants'
       WRITE(6,1004)
1004 FORMAT('TEMP    Z0        N          M1        Z1        R1        ',
    > 'A1 ')
       DO I=1,NTEMM
         WRITE(6,1005) TEMPROPM(I),Z0D(I),BND(I),BM1D(I),Z1D(I),
    >                    R1D(I),A1D(I)
         END DO
       WRITE(6,*)
       WRITE(6,1006)
       DO I=1,NTEMM
         WRITE(6,1007) TEMPROPM(I),BM2D(I),Z2D(I),R2D(I),A2D(I),
    >                       Z3D(I)
         END DO
       WRITE(6,*)
       WRITE(6,*)
       WRITE(6,*)
       WRITE(6,*)  '        Interfacial damage characteristics '
       WRITE(6,*)
```

```
      WRITE(6,*) 'SIC = ', SIC
      WRITE(6,*)
      WRITE(6,1008)
1008 FORMAT(' TEMP      SF1      UF1/a')
        DO I=1,NTEMI
        WRITE(6,1009) TEMPROPI(I),SIFN1(I),UIFN1OA(I)
        WRITE(6,1010) SIFT1(I),UIFT1OA(I)
        END DO
1003 FORMAT(2F3.0,2F11.1,F11.4,F11.1,F11.3)
1005 FORMAT(7F11.3)
1006 FORMAT('TEMP     M2         Z2         R2        A2        Z3')
1007 FORMAT(6F11.3)
1009 FORMAT(F10.2,F10.2,F10.5)
1010 FORMAT(T11,F10.2,F10.5)
        READ(5,*)

     ELSE IF(NP.EQ.6) THEN

        RETURN

     ELSE

       GO TO 2

     END IF

     END
C
C
C  * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C     The subroutine READDAT reads either a machine dependent
C  unformatted file of a solution set from an FTS calculation or
C  a global ASCII file that may be read by any machine.
C
C  * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C

     SUBROUTINE READDAT

     CHARACTER FIB*1,MATE*1,MATP*1,MATV*1,TCHARP*1,TCHARV*1,
    >COMP*40, ECHAR*1, LCHAR*1

     COMMON/TYPEMOD/NA,NUMPLY,ZPOS(7),ANGLE(6)

     COMMON/MATERIAL/NUF12(40),NUF23(40),NUM12(40),NUM23(40),GM12(40),
    >EM22(40),EM11(40),AR,VF,GF12(40),EF22(40),EF11(40),HPRAMPTS(40),
    >YSPTS(40),TEMPROPF(40),TEMPROPM(40),NTEMF,NTEMM,HD,ALPHAF1(40),
    >ALPHAF2(40),ALPHAM1(40),ALPHAM2(40),OSAT(40),F1(40),F3(40),Z0(40),
    >BN(40),DNOT,Z0D(40),BND(40),BM1D(40),Z1D(40),R1D(40),
    >A1D(40),BM2D(40),Z2D(40),R2D(40),A2D(40),Z3D(40),TEMPREF,NTEMI,
    >SIC,TEMPROPI(40),SIFN1(40),UIFN1OA(40),SIFT1(40),UIFT1OA(40)
```

```
      COMMON/LOADING/NC1,NC2,NUMP,NUMCYC,DT(9999),TEMP(9999),NX(9999),
     >NY(9999),NXY(9999),M(9999)

      COMMON/ELASTPROP/SSF11(40),SSF22(40),SSF12(40),SSF23(40),
     >SSF44(40),SSM11(40),SSM22(40),SSM12(40),SSM23(40),SSM44(40),
     >A(6),B(6),C(6)

      COMMON/TOLERANCE/TOLP1,TOLP2,TOLP3,TOLV1,TOLV2,TOLV3,TOLV4

      COMMON/WORDS/FIB,MATE,MATP,MATV,TCHARP,TCHARV,COMP,ECHAR,LCHAR

      REAL  NX(9999),NY(9999),NXY(9999),EPSCOM(3),SIGPLY(6,3),EPSF(6,4),
     >SF(6,4),EPSM(6,3,4),SM(6,3,4),UI(6,2,2),SI(6,2,2),NUF12(40),
     >NUF23(40),NUM12(40),NUM23(40)

      CHARACTER INDAT*15



 2    REWIND 8

        WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
            WRITE(6,*) '   * * * * * * * * * * * * * * * * * '
            WRITE(6,*) '   *  Read Results from a File    * '
            WRITE(6,*) '   * * * * * * * * * * * * * * * * * '
            WRITE(6,*)
            WRITE(6,*)
            WRITE(6,*) '     (1) Unformatted file '
            WRITE(6,*) '     **N/A**(2) Global ASCII file '
            WRITE(6,*) '     (3) Return to results menu '
      WRITE(6,*)
      WRITE(6,*)
      WRITE(6,*) '  Enter Selection:  '
        READ(5,*) ND


      IF(ND.EQ.1) THEN

       WRITE(6,*)' Enter name of the unformatted file to be read.'
        READ(5,201) INDAT
201   FORMAT(A15)
          OPEN(40,FILE=INDAT,STATUS='OLD',FORM='UNFORMATTED')
        READ(40) NA,NUMPLY,NTEMF,NTEMM,NTEMI,AR,VF,HD,DNOT,SIC
     >        TEMPREF,NC1,NC2,NUMP,NUMCYC,FIB,MATE,MATP,MATV,TCHARP,
     >        TCHARV,COMP,ECHAR,LCHAR
          READ(40)  (ZPOS(I),I=1,NUMPLY+1),(ANGLE(J),J=1,NUMPLY)
```

```
      READ(40)  (TEMPROPF(I),NUF12(I),NUF23(I),GF12(I),EF22(I),
>                EF11(I),ALPHAF1(I),ALPHAF2(I),I=1,NTEMF)
      READ(40)  (TEMPROPM(I),NUM12(I),NUM23(I),GM12(I),EM22(I),
>                EM11(I),ALPHAM1(I),ALPHAM2(I),HPRAMPTS(I),YSPTS(I),
>                OSAT(I),F1(I),F3(I),Z0(I),BN(I),Z0D(I),BND(I),
>                BM1D(I),Z1D(I),R1D(I),A1D(I),BM2D(I),Z2D(I),
>                R2D(I),A2D(I),Z3D(I),I=1,NTEMM)
      READ(40)  (TEMPROPI(I),SIFN1(I),UIFN1OA(I),
>                SIFT1(I),UIFT1OA(I),I=1,NTEMI)

    DO I=1,NUMP
      READ(40) DT(I),TEMP(I),NX(I),NY(I),NXY(I),M(I)
    END DO

        DO N=1,NC1-1
         READ(40) TIM1,TEM1,(EPSCOM(K),K=1,3),PNX,PNY,PNXY,
>((SIGPLY(I,K),K=1,3),(EPSF(I,K),SF(I,K),K=1,4),((EPSM(I,J,K),
>SM(I,J,K),K=1,4),J=1,3),((UI(I,J,K),SI(I,J,K),K=1,2),J=1,2),
>I=1,NUMPLY)

         WRITE(8) TIM1,TEM1,(EPSCOM(K),K=1,3),PNX,PNY,PNXY,
>((SIGPLY(I,K),K=1,3),(EPSF(I,K),SF(I,K),K=1,4),((EPSM(I,J,K),
>SM(I,J,K),K=1,4),J=1,3),((UI(I,J,K),SI(I,J,K),K=1,2),J=1,2),
>I=1,NUMPLY)


        END DO

      DO NCYC=1,NUMCYC

        DO N=NC1,NC2
         READ(40) TIM1,TEM1,(EPSCOM(K),K=1,3),PNX,PNY,PNXY,
>((SIGPLY(I,K),K=1,3),(EPSF(I,K),SF(I,K),K=1,4),((EPSM(I,J,K),
>SM(I,J,K),K=1,4),J=1,3),((UI(I,J,K),SI(I,J,K),K=1,2),J=1,2),
>I=1,NUMPLY)

         WRITE(8) TIM1,TEM1,(EPSCOM(K),K=1,3),PNX,PNY,PNXY,
>((SIGPLY(I,K),K=1,3),(EPSF(I,K),SF(I,K),K=1,4),((EPSM(I,J,K),
>SM(I,J,K),K=1,4),J=1,3),((UI(I,J,K),SI(I,J,K),K=1,2),J=1,2),
>I=1,NUMPLY)

        END DO

      END DO

      DO N=NC2+1,NUMP
         READ(40) TIM1,TEM1,(EPSCOM(K),K=1,3),PNX,PNY,PNXY,
>((SIGPLY(I,K),K=1,3),(EPSF(I,K),SF(I,K),K=1,4),((EPSM(I,J,K),
>SM(I,J,K),K=1,4),J=1,3),((UI(I,J,K),SI(I,J,K),K=1,2),J=1,2),
>I=1,NUMPLY)

         WRITE(8) TIM1,TEM1,(EPSCOM(K),K=1,3),PNX,PNY,PNXY,
>((SIGPLY(I,K),K=1,3),(EPSF(I,K),SF(I,K),K=1,4),((EPSM(I,J,K),
>SM(I,J,K),K=1,4),J=1,3),((UI(I,J,K),SI(I,J,K),K=1,2),J=1,2),
```

```
     >I=1,NUMPLY)
            END DO

       ELSEIF(ND.EQ.2) THEN

       ELSEIF(ND.EQ.3) THEN
         RETURN
       END IF
       GO TO 2
       END
C
C
C  * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C     The subroutine RESULT examines the most recent solution from the
C  present session or past solutions that have been saved to a formatted
C  file.  The most recent solution may also be saved to a formatted or
C  unformatted file using this subroutine.
C
C  * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C

       SUBROUTINE RESULT

       REAL NUF12(40), NUF23(40), NUM12(40), NUM23(40),NX(9999),
      >NY(9999),NXY(9999)

       CHARACTER FIB*1,MATE*1,MATP*1,MATV*1,TCHARP*1,TCHARV*1,
      >COMP*40, ECHAR*1, LCHAR*1

       COMMON/TYPEMOD/NA,NUMPLY,ZPOS(7),ANGLE(6)

       COMMON/MATERIAL/NUF12(40),NUF23(40),NUM12(40),NUM23(40),GM12(40),
      >EM22(40),EM11(40),AR,VF,GF12(40),EF22(40),EF11(40),HPRAMPTS(40),
      >YSPTS(40),TEMPROPF(40),TEMPROPM(40),NTEMF,NTEMM,HD,ALPHAF1(40),
      >ALPHAF2(40),ALPHAM1(40),ALPHAM2(40),OSAT(40),F1(40),F3(40),Z0(40),
      >BN(40),DNOT,Z0D(40),BND(40),BM1D(40),Z1D(40),R1D(40),
      >A1D(40),BM2D(40),Z2D(40),R2D(40),A2D(40),Z3D(40),TEMPREF,NTEMI,
      >SIC,TEMPROPI(40),SIFN1(40),UIFN1OA(40),SIFT1(40),UIFT1OA(40)

       COMMON/LOADING/NC1,NC2,NUMP,NUMCYC,DT(9999),TEMP(9999),NX(9999),
      >NY(9999),NXY(9999),M(9999)
```

```
      COMMON/ELASTPROP/SSF11(40),SSF22(40),SSF12(40),SSF23(40),
     >SSF44(40),SSM11(40),SSM22(40),SSM12(40),SSM23(40),SSM44(40),
     >A(6),B(6),C(6)

      COMMON/TOLERANCE/TOLP1,TOLP2,TOLP3,TOLV1,TOLV2,TOLV3,TOLV4

      COMMON/WORDS/FIB,MATE,MATP,MATV,TCHARP,TCHARV,COMP,ECHAR,LCHAR




1       WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
        WRITE(6,*)
            WRITE(6,*) '   * * * * * * * * * * * * * * * * * '
            WRITE(6,*) '   *     Results of Solution     * '
            WRITE(6,*) '   * * * * * * * * * * * * * * * * * '
            WRITE(6,*)
            WRITE(6,*)
            WRITE(6,*) '      (1) Read saved results file '
            WRITE(6,*) '      (2) Write existing data to a file '
      WRITE(6,*) '      (3) Create Tables '
            WRITE(6,*) '      (4) Return to main menu '
      WRITE(6,*)
      WRITE(6,*)
      WRITE(6,*) '  Enter Selection:  '
        READ(5,*) NS

        IF(NS.EQ.1) THEN

          CALL READDAT

      ELSEIF(NS.EQ.2) THEN

        CALL WRITEDAT

      ELSEIF(NS.EQ.3) THEN

        IF(LCHAR.NE.'Y') THEN
          WRITE(6,*)
          WRITE(6,*)' No dataset has been calculated.'
```

```
          WRITE(6,*)

        ELSE

          CALL TABLE

        END IF

      ELSEIF(NS.EQ.4) THEN

        RETURN


      END IF

        GO TO 1

      END
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C     The SOLV subroutine determines the composite response to a given
C  thermomechanical load history for a LISOL model.
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C


      SUBROUTINE SOLV


      REAL NUF12(40), NUF23(40), NUM12(40), NUM23(40)

      CHARACTER FIB*1,MATE*1,MATP*1,MATV*1,TCHARP*1,TCHARV*1,
     >COMP*40, ECHAR*1,LCHAR*1

      COMMON/TYPEMOD/NA,NUMPLY,ZPOS(7),ANGLE(6)

      COMMON/MATERIAL/NUF12(40),NUF23(40),NUM12(40),NUM23(40),GM12(40),
     >EM22(40),EM11(40),AR,VF,GF12(40),EF22(40),EF11(40),HPRAMPTS(40),
     >YSPTS(40),TEMPROPF(40),TEMPROPM(40),NTEMF,NTEMM,HD,ALPHAF1(40),
     >ALPHAF2(40),ALPHAM1(40),ALPHAM2(40),OSAT(40),F1(40),F3(40),Z0(40),
     >BN(40),DNOT,Z0D(40),BND(40),BM1D(40),Z1D(40),R1D(40),
     >A1D(40),BM2D(40),Z2D(40),R2D(40),A2D(40),Z3D(40),TEMPREF,NTEMI,
     >SIC,TEMPROPI(40),SIFN1(40),UIFN1OA(40),SIFT1(40),UIFT1OA(40)

      COMMON/LOADING/NC1,NC2,NUMP,NUMCYC,DT(9999),TEMP(9999),NX(9999),
     >NY(9999),NXY(9999),M(9999)

      COMMON/ELASTPROP/SSF11(40),SSF22(40),SSF12(40),SSF23(40),
     >SSF44(40),SSM11(40),SSM22(40),SSM12(40),SSM23(40),SSM44(40),
     >A(6),B(6),C(6)
```

```
      COMMON/TOLERANCE/TOLP1,TOLP2,TOLP3,TOLV1,TOLV2,TOLV3,TOLV4

      REAL BIGT(50,20),NX(9999),NY(9999),NXY(9999),K2(6,3),LVEC0(50)

      COMMON/VISCOPLAST/H(50,50),HINV(50,50),T(6,3,3),TINT(6,3,3),
     >TH(50,20),BIGP(50,50),N,NCYC,TEM0,TIM0,PZI(6,3),LVEC0(50),
     >EPSMP0(6,3,4),SM0(6,3,4),UIF0(6,2,2),SI0(6,2,2),UI0(6,2,2),
     >K2(6,3),BETA0(6,3,4),OMEG0(6,3,4),EPSTHM1,EPSTHM2,EPSTHF1,
     >EPSTHF2,NDUMP

      COMMON/WORDS/FIB,MATE,MATP,MATV,TCHARP,TCHARV,COMP,ECHAR,LCHAR

C
C
C   Find the dimensions of the representative volume element
C
C

       DO I=1,NUMPLY
        A(I) = (ZPOS(I+1)-ZPOS(I))*SQRT(VF/AR)
        C(I) = ZPOS(I+1)-ZPOS(I)-A(I)
      B(I) = (A(I)+C(I))/AR-A(I)
       END DO


C
C
C
C  Use property relations to find the fiber and matrix compliance
C  matrices.  Also, converts compliance to units of 1/MPa.
C
C

        CONVER = 10.**(-3)

      DO N=1,NTEMF

        SSF11(N) = 1/EF11(N)
        SSF22(N) = 1/EF22(N)
        SSF12(N) = -NUF12(N)/EF11(N)
        SSF23(N) = -NUF23(N)/EF22(N)
      SSF44(N) = 1/GF12(N)

        SSF11(N) = SSF11(N)*CONVER
        SSF22(N) = SSF22(N)*CONVER
        SSF12(N) = SSF12(N)*CONVER
        SSF23(N) = SSF23(N)*CONVER
      SSF44(N) = SSF44(N)*CONVER

      END DO

      DO N=1,NTEMM

        SSM11(N) = 1/EM11(N)
        SSM22(N) = 1/EM22(N)
```

```
      SSM12(N)  =  -NUM12(N)/EM11(N)
      SSM23(N)  =  -NUM23(N)/EM22(N)
    SSM44(N)  =  1/GM12(N)

      SSM11(N)  =  SSM11(N)*CONVER
      SSM22(N)  =  SSM22(N)*CONVER
      SSM12(N)  =  SSM12(N)*CONVER
      SSM23(N)  =  SSM23(N)*CONVER
    SSM44(N)  =  SSM44(N)*CONVER

    END DO

C
C      Set the zero stress thermal strains
C

        AM1  =  TDEP(NTEMM,TEMPROPM,ALPHAM1,TEMP(1))
      AF1  =  TDEP(NTEMF,TEMPROPF,ALPHAF1,TEMP(1))
      AM2  =  TDEP(NTEMM,TEMPROPM,ALPHAM2,TEMP(1))
      AF2  =  TDEP(NTEMF,TEMPROPF,ALPHAF2,TEMP(1))
      EPSTHM1  =  AM1*(TEMP(1)-TEMPREF)
      EPSTHF1  =  AF1*(TEMP(1)-TEMPREF)
      EPSTHM2  =  AM2*(TEMP(1)-TEMPREF)
      EPSTHF2  =  AF2*(TEMP(1)-TEMPREF)


C
C    ENTER THE [H] AND [T] MATRICES AND DETERMINE THE [TH] MATRIX
C

        DO N=1,NUMPLY
        H(1,3*N-2)=ZPOS(N+1)-ZPOS(N)
        H(1,3*N-1)=0.
        H(1,3*N)=0.
        H(2,3*N-2)=0.
        H(2,3*N-1)=ZPOS(N+1)-ZPOS(N)
        H(2,3*N)=0.
        H(3,3*N-2)=0.
        H(3,3*N-1)=0.
        H(3,3*N)=ZPOS(N+1)-ZPOS(N)
        H(4,3*N-2)=0.5*(ZPOS(N+1)**2.-ZPOS(N)**2.)
        H(4,3*N-1)=0.
        H(4,3*N)=0.
        H(5,3*N-2)=0.
        H(5,3*N-1)=0.5*(ZPOS(N+1)**2.-ZPOS(N)**2.)
        H(5,3*N)=0.
        H(6,3*N-2)=0.
        H(6,3*N-1)=0.
        H(6,3*N)=0.5*(ZPOS(N+1)**2.-ZPOS(N)**2.)
      END DO
      DO N=7,3*NUMPLY
        DO I=1,3*NUMPLY
          H(N,I)=0.
        END DO
```

```
      END DO
      DO N=7,3*NUMPLY
        H(N,N)=1.
      END DO

      DO N=1,NUMPLY
        CS=COSD(ANGLE(N))
        SN=SIND(ANGLE(N))
        T(N,1,1)=CS**2.
        T(N,1,2)=SN**2.
        T(N,1,3)=2.*SN*CS
        T(N,2,1)=T(N,1,2)
        T(N,2,2)=T(N,1,1)
        T(N,2,3)=-T(N,1,3)
        T(N,3,1)=-SN*CS
        T(N,3,2)=-T(N,3,1)
        T(N,3,3)=CS**2.-SN**2.
      END DO

C
C  INVERSE-TRANSPOSE OF THE [T] MATRIX
C

      DO N=1,NUMPLY
        TINT(N,1,1)=T(N,1,1)
        TINT(N,1,2)=T(N,1,2)
        TINT(N,1,3)=T(N,1,3)/2.
        TINT(N,2,1)=T(N,2,1)
        TINT(N,2,2)=T(N,2,2)
        TINT(N,2,3)=T(N,2,3)/2.
        TINT(N,3,1)=T(N,3,1)*2.
        TINT(N,3,2)=T(N,3,2)*2.
        TINT(N,3,3)=T(N,3,3)
      END DO

      NPLY3=3*NUMPLY

    CALL INVERSE(NPLY3,H,HINV)

    DO N=1,8*NUMPLY
      DO I=1,3*NUMPLY
      BIGT(N,I)=0.
    END DO
    END DO

    DO N=1,NUMPLY
      BIGT(8*N-2,3*N-2)=T(N,1,1)
      BIGT(8*N-2,3*N-1)=T(N,1,2)
      BIGT(8*N-2,3*N)=T(N,1,3)
      BIGT(8*N-1,3*N-2)=T(N,2,1)
      BIGT(8*N-1,3*N-1)=T(N,2,2)
      BIGT(8*N-1,3*N)=T(N,2,3)
      BIGT(8*N,3*N-2)=T(N,3,1)
      BIGT(8*N,3*N-1)=T(N,3,2)
```

```
        BIGT(8*N,3*N)=T(N,3,3)
      END DO

C
C  DETERMINE THE [TH] MATRIX BY MATRIX MULTIPLICATION
C

      DO N=1,8*NUMPLY
        DO I=1,3*NUMPLY
        TH(N,I)=0.
          DO J=1,3*NUMPLY
            TH(N,I)=TH(N,I)+BIGT(N,J)*HINV(J,I)
          END DO
      END DO
      END DO

C
C  ENTER COMPONENTS OF [TH] THAT APPEAR IN THE [BIGP] MATRIX
C

      DO I=5*NUMPLY+7,8*NUMPLY
        DO N=1,8*NUMPLY
        BIGP(N,I)=-TH(N,I-5*NUMPLY)
      END DO
      END DO

C
C  Initialize the components of the BIGP matrix containing the PB
C  matrices
C

      DO I=1,5*NUMPLY
        DO J=1,8*NUMPLY
        BIGP(J,I+6)=0.0
      END DO
      END DO

C
C
C     Perform calculations.
C
C


       IF(NA.EQ.1) THEN

C
C
C       Linear Elastic Case.
C
C


       ELSEIF(NA.EQ.2) THEN
```

```
C
C
C     Elastic-Plastic case
C
C


       ELSEIF(NA.EQ.3) THEN
C
C
C    Viscoplastic case
C
C
C    Set initial values for some of the variables for the first
C    increment.
C
C
       TEM0=TEMP(1)
       TIM0=0.
       IF(DT(1).EQ.0.0) DT(1) = 0.000001
         NCYC=0
       NDUMP=0
       DO I=1,NUMPLY
         DO J=1,3
           PZI(I,J)=0.0
         END DO
       END DO
       DO I=1,8*NUMPLY
         LVEC0(I)=0.
       END DO
       DO I=1,NUMPLY
         DO J=1,3
           DO K=1,4
             EPSMP0(I,J,K)=0.
             BETA0(I,J,K)=0.
             OMEG0(I,J,K)=0.
             SM0(I,J,K)=0.
           END DO
           K2(I,J)=0.0
         END DO
         DO K=1,2
           UIF0(I,K,1)=0.0000001
           UIF0(I,K,2)=0.0000001
           DO J=1,2
             SI0(I,K,J)=0.0
             UI0(I,K,J)=0.0
           END DO
         END DO
       END DO

         DO N=1,NC1-1


         CALL VISC
```

```
        IF(NDUMP.EQ.1) RETURN

        END DO
C
C
C     Perform cyclic loading sequence
C
C

        DO NCYC=1,NUMCYC
          WRITE(6,*)'CYCLE ',NCYC
        DO N=NC1,NC2

          CALL VISC
          IF(NDUMP.EQ.1) RETURN

        END DO

      END DO
C
C
C     Perform the post-load sequence
C
C

        DO N=NC2+1,NUMP

        CALL VISC
        IF(NDUMP.EQ.1) RETURN

      END DO


      END IF

      RETURN

      END
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C    The subroutine STRESS calculates the stresses for a LISOL
C  model given a plastic strain and the solution to the matrix equation.
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

```
C
C

      SUBROUTINE STRESS(NUMPLY,EPSMP,XVEC,TINT,A,B,C,SM,SF,SI,SPLY,
     >SSIT,S44F,S11M,S12M,S44M)

      REAL EPSMP(6,3,4),XVEC(50),TINT(6,3,3),A(6),B(6),C(6),
     >SM(6,3,4),SF(6,4),SI(6,2,2),SPLY(6,3),SSIT(6,2),GAM(6)

      INTEGER NUMPLY


      R1 = S11M/S12M

      DO I=1,NUMPLY
        I5=5*I
        SF(I,1)=XVEC(I5+2)
      SF(I,2)=XVEC(I5+3)
      SM(I,1,1)=XVEC(I5+4)
      SM(I,1,3)=XVEC(I5+5)
      SM(I,2,1)=XVEC(I5+6)

      SF(I,3)=-B(I)/A(I)*SM(I,1,3)
      SM(I,1,2)=SF(I,2)
      SM(I,2,2)=SM(I,1,2)+R1*SM(I,1,1)-R1*SM(I,2,1)+EPSMP(I,1,1)
     >     /S12M - EPSMP(I,2,1)/S12M
        SI(I,1,1)=SF(I,2)
      SM(I,2,3)=SM(I,1,3)
      SM(I,3,2)=SM(I,2,2)
      SM(I,3,3)=SF(I,3)
      SI(I,2,1)=SF(I,3)
      SM(I,3,1)=SM(I,2,1)+SM(I,2,3)/R1-SM(I,3,3)/R1+
     >     EPSMP(I,2,1)/S11M-EPSMP(I,3,1)/S11M

        GAM(I)=TINT(I,3,1)*XVEC(1)+TINT(I,3,2)*XVEC(2)+
     >          TINT(I,3,3)*XVEC(3)

      T4=C(I)/A(I)

        AA=(1+T4)*(S44F+SSIT(I,1))
      BB=S44M+T4*(S44F+SSIT(I,1))

        D1=S44M*(A(I)*AA/BB+B(I))
      SPLY(I,3)=(A(I)+B(I))*GAM(I)/D1 - B(I)*EPSMP(I,1,4)/(D1*(1+T4))
     >   - B(I)*T4*EPSMP(I,2,4)/(D1*(1+T4)) - A(I)*(1-S44M/BB)*
     >   EPSMP(I,3,4)/D1

        SM(I,3,4)=AA/BB*SPLY(I,3)-EPSMP(I,3,4)/BB
      SF(I,4)=(1+T4)*SPLY(I,3) - T4*SM(I,3,4)
      SM(I,2,4)=SPLY(I,3)+(EPSMP(I,1,4)-EPSMP(I,2,4))/(S44M*(1+T4))
      SM(I,1,4)=(1+T4)*SPLY(I,3) - T4*SM(I,2,4)
      SI(I,1,2)=SF(I,4)
      SI(I,2,2)=0.
```

```
      END DO


      RETURN

      END
C
C  * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C     The subroutine TABLE creates tables of results from an LISOL
C  solution.
C
C  * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C

      SUBROUTINE TABLE


      COMMON/TYPEMOD/NA,NUMPLY,ZPOS(7),ANGLE(6)

      COMMON/LOADING/NC1,NC2,NUMP,NUMCYC,DT(9999),TEMP(9999),NX(9999),
     >NY(9999),NXY(9999),M(9999)

      REAL  SC(3),EPSCOM(3),SIGPLY(6,3),SF(6,4),EPSF(6,4),SM(6,3,4),
     >EPSM(6,3,4),SI(6,2,2),UI(6,2,2),TBL(10),NX(9999),NY(9999),
     >NXY(9999)

      INTEGER ITYP(10),ICOM(10)

      CHARACTER CHAR1(100)*18,CHAR2(20)*18,OUTFIL*20


      REWIND 8



      WRITE(6,*)
      WRITE(6,*)' How many columns in new table (<=7)?'
      READ(5,*) NCOL

      DO LL=1,NCOL
        ICOM(LL)=0
      END DO

      NUMM=3

      DO I=1,NCOL

      WRITE(6,1001)
 1001 FORMAT(/////,'                                   (1) Time',/,
     >'                            (2) Temperature',//,
     >'          Composite:        (3) Stress        (4) Strain')
```

```
      DO IP=1,NUMPLY
        WRITE(6,1011) IP,14*IP-9,14*IP-8
1011 FORMAT('                Ply : ',I1,5X,'(',I2,') Stress       (',
     > I2,') Strain')

      WRITE(6,1002) 14*IP-7,14*IP-6
1002 FORMAT('     Fiber Region  :',5X,'(',I2,') Stress       (',I2,
     >') Strain')

      DO IIM=1,NUMM
        WRITE(6,1003) IIM,14*IP+2*IIM-7,14*IP+2*IIM-6
1003 FORMAT('    Matrix Region',I2,':',6X,'(',I2,') Stress       (',
     >I2,') Strain')
      END DO

      DO III = 1,NUMM-1
        WRITE(6,1010) III,14*IP+2*III-1,14*IP+2*III
1010 FORMAT(' Interface Region',I2,':',6X,'(',I2,') Stress       (',
     >I2,') Displacement')
      END DO
      WRITE(6,*)

      END DO


      WRITE(6,1004) I
1004 FORMAT(//,'  Select desired quantity for column ',I2)

      READ(5,*) ITYP(I)

      IF(ITYP(I).GT.2) THEN
       WRITE(6,1005)
1005 FORMAT(//,'          Component:  (1) 1-1, X   (2) 2-2, Y    ',
     >'(3) 3-3, XY    (4) 1-2',//,
     >'      Select stress/strain component:')
       READ(5,*) ICOM(I)
      END IF

      END DO

      WRITE(6,*)
      WRITE(6,1008)
1008 FORMAT(' Write table to  (1) screen   (2) file   (3) both',
     >'    (4) Cancel')
      READ(5,*) IOUT

      IF(IOUT.EQ.4) RETURN

      IF(IOUT.NE.1) THEN
        WRITE(6,*)'Enter the name of the file'
        READ(5,2222) OUTFIL
2222 FORMAT(A20)
        OPEN(20,FILE=OUTFIL,STATUS='NEW')
      END IF
```

```
      CHAR1(1) = 'Time (sec)'
      CHAR1(2) = 'Temperature (C)'
      CHAR1(3) = 'Composite Stress'
      CHAR1(4) = 'Composite Strain'

      CHAR1(5) = 'Ply  1  Stress'
      CHAR1(6) = 'Ply  1  Strain'
      CHAR1(19) = 'Ply  2  Stress'
      CHAR1(20) = 'Ply  2  Strain'
      CHAR1(33) = 'Ply  3  Stress'
      CHAR1(34) = 'Ply  3  Strain'
      CHAR1(47) = 'Ply  4  Stress'
      CHAR1(48) = 'Ply  4  Strain'
      CHAR1(61) = 'Ply  5  Stress'
      CHAR1(62) = 'Ply  5  Strain'
      CHAR1(75) = 'Ply  6  Stress'
      CHAR1(76) = 'Ply  6  Strain'

      DO IP=1,NUMPLY

      CHAR1(14*IP-7) = 'Fib  Reg  Stress'
      CHAR1(14*IP-6) = 'Fib  Reg  Strain'
      CHAR1(14*IP-5) = 'Mat Reg 1 Stress'
      CHAR1(14*IP-4) = 'Mat Reg 1 Strain'
      CHAR1(14*IP-3) = 'Mat Reg 2 Stress'
      CHAR1(14*IP-2) = 'Mat Reg 2 Strain'
      CHAR1(14*IP-1) = 'Mat Reg 3 Stress'
      CHAR1(14*IP) = 'Mat Reg 3 Strain'
      CHAR1(14*IP+1) = 'Int Reg 1 Stress'
      CHAR1(14*IP+2) = 'Int Reg 1 Dsplmt'
      CHAR1(14*IP+3) = 'Int Reg 2 Stress'
      CHAR1(14*IP+4) = 'Int Reg 2 Dsplmt'

      END DO

      CHAR2(0) = ''
      CHAR2(1) = 'Component 1-1/XX'
      CHAR2(2) = 'Component 2-2/YY'
      CHAR2(3) = 'Component 3-3/XY'
      CHAR2(4) = 'Component 1-2'


      IF(IOUT.NE.2) THEN
        WRITE(6,1006) (CHAR1(ITYP(I)),I=1,NCOL)
 1006 FORMAT(7(2X,A16))
 1009 FORMAT(7(2X,A16),/)
        WRITE(6,1009) (CHAR2(ICOM(I)),I=1,NCOL)
      END IF

      IF(IOUT.NE.1) THEN
        WRITE(20,1006) (CHAR1(ITYP(I)),I=1,NCOL)
        WRITE(20,1009) (CHAR2(ICOM(I)),I=1,NCOL)
      END IF
```

```
      DO N=1,NC1-1
        READ(8) TIM1,TEM1,(EPSCOM(K),K=1,3),(SC(K),K=1,3),
     >((SIGPLY(I,K),K=1,3),(EPSF(I,K),SF(I,K),K=1,4),((EPSM(I,J,K),
     >SM(I,J,K),K=1,4),J=1,3),((UI(I,J,K),SI(I,J,K),K=1,2),J=1,2),
     >I=1,NUMPLY)

       DO I=1,NCOL
         IF(ITYP(I).EQ.1) TBL(I)=TIM1
         IF(ITYP(I).EQ.2) TBL(I)=TEM1
         IF(ITYP(I).EQ.3) TBL(I)=SC(ICOM(I))
         IF(ITYP(I).EQ.4) TBL(I)=EPSCOM(ICOM(I))

         DO IP=1,NUMPLY

           IF(ITYP(I).EQ.14*IP-9) TBL(I)=SIGPLY(IP,ICOM(I))
           IF(ITYP(I).EQ.14*IP-8) TBL(I)=EPSCOM(ICOM(I))
           IF(ITYP(I).EQ.14*IP-7) TBL(I)=SF(IP,ICOM(I))
           IF(ITYP(I).EQ.14*IP-6) TBL(I)=EPSF(IP,ICOM(I))

           DO IIM=1,NUMM
             IF(ITYP(I).EQ.14*IP+2*IIM-7) TBL(I)=SM(IP,IIM,ICOM(I))
             IF(ITYP(I).EQ.14*IP+2*IIM-6) TBL(I)=EPSM(IP,IIM,
     >              ICOM(I))
           END DO

           DO III = 1,NUMM-1
             IF(ITYP(I).EQ.14*IP+2*III-1) TBL(I)=SI(IP,III,ICOM(I))
             IF(ITYP(I).EQ.14*IP+2*III) TBL(I)=UI(IP,III,ICOM(I))
           END DO

         END DO

       END DO

       IF(IOUT.NE.2) THEN
         WRITE(6,1007) (TBL(I),I=1,NCOL)
 1007 FORMAT(7F18.9)
         END IF

       IF(IOUT.NE.1) THEN
         WRITE(20,1007) (TBL(I),I=1,NCOL)
         END IF

      END DO

     DO NCYC=1,NUMCYC

      DO N=NC1,NC2
        READ(8) TIM1,TEM1,(EPSCOM(K),K=1,3),(SC(K),K=1,3),
     >((SIGPLY(I,K),K=1,3),(EPSF(I,K),SF(I,K),K=1,4),((EPSM(I,J,K),
     >SM(I,J,K),K=1,4),J=1,3),((UI(I,J,K),SI(I,J,K),K=1,2),J=1,2),
     >I=1,NUMPLY)
```

```
          DO I=1,NCOL
            IF(ITYP(I).EQ.1) TBL(I)=TIM1
            IF(ITYP(I).EQ.2) TBL(I)=TEM1
            IF(ITYP(I).EQ.3) TBL(I)=SC(ICOM(I))
            IF(ITYP(I).EQ.4) TBL(I)=EPSCOM(ICOM(I))

            DO IP=1,NUMPLY

              IF(ITYP(I).EQ.14*IP-9) TBL(I)=SIGPLY(IP,ICOM(I))
              IF(ITYP(I).EQ.14*IP-8) TBL(I)=EPSCOM(ICOM(I))
              IF(ITYP(I).EQ.14*IP-7) TBL(I)=SF(IP,ICOM(I))
              IF(ITYP(I).EQ.14*IP-6) TBL(I)=EPSF(IP,ICOM(I))

              DO IIM=1,NUMM
                IF(ITYP(I).EQ.14*IP+2*IIM-7) TBL(I)=SM(IP,IIM,ICOM(I))
                IF(ITYP(I).EQ.14*IP+2*IIM-6) TBL(I)=EPSM(IP,IIM,
>                     ICOM(I))
              END DO

              DO III = 1,NUMM-1
                IF(ITYP(I).EQ.14*IP+2*III-1) TBL(I)=SI(IP,III,ICOM(I))
                IF(ITYP(I).EQ.14*IP+2*III) TBL(I)=UI(IP,III,ICOM(I))
              END DO

            END DO

          END DO

          IF(IOUT.NE.2) THEN
            WRITE(6,1007) (TBL(I),I=1,NCOL)
            END IF

          IF(IOUT.NE.1) THEN
            WRITE(20,1007) (TBL(I),I=1,NCOL)
            END IF

        END DO

      END DO

      DO N=NC2+1,NUMP
          READ(8) TIM1,TEM1,(EPSCOM(K),K=1,3),(SC(K),K=1,3),
>((SIGPLY(I,K),K=1,3),(EPSF(I,K),SF(I,K),K=1,4),((EPSM(I,J,K),
>SM(I,J,K),K=1,4),J=1,3),((UI(I,J,K),SI(I,J,K),K=1,2),J=1,2),
>I=1,NUMPLY)

          DO I=1,NCOL
            IF(ITYP(I).EQ.1) TBL(I)=TIM1
            IF(ITYP(I).EQ.2) TBL(I)=TEM1
            IF(ITYP(I).EQ.3) TBL(I)=SC(ICOM(I))
            IF(ITYP(I).EQ.4) TBL(I)=EPSCOM(ICOM(I))

            DO IP=1,NUMPLY
```

```
          IF(ITYP(I).EQ.14*IP-9) TBL(I)=SIGPLY(IP,ICOM(I))
          IF(ITYP(I).EQ.14*IP-8) TBL(I)=EPSCOM(ICOM(I))
          IF(ITYP(I).EQ.14*IP-7) TBL(I)=SF(IP,ICOM(I))
          IF(ITYP(I).EQ.14*IP-6) TBL(I)=EPSF(IP,ICOM(I))

          DO IIM=1,NUMM
            IF(ITYP(I).EQ.14*IP+2*IIM-7) TBL(I)=SM(IP,IIM,ICOM(I))
            IF(ITYP(I).EQ.14*IP+2*IIM-6) TBL(I)=EPSM(IP,IIM,
     >            ICOM(I))
          END DO

          DO III = 1,NUMM-1
            IF(ITYP(I).EQ.14*IP+2*III-1) TBL(I)=SI(IP,III,ICOM(I))
            IF(ITYP(I).EQ.14*IP+2*III) TBL(I)=UI(IP,III,ICOM(I))
          END DO

        END DO

      END DO

      IF(IOUT.NE.2) THEN
        WRITE(6,1007) (TBL(I),I=1,NCOL)
        END IF

      IF(IOUT.NE.1) THEN
        WRITE(20,1007) (TBL(I),I=1,NCOL)
        END IF

     END DO

   IF(IOUT.NE.2) THEN
     READ(5,*)
   END IF


   RETURN

   END
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C  This function calculates the temperature dependent properties
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
   FUNCTION TDEP(NTEM,TEMPROP,YSPTS,TEMP)

   REAL TEMPROP(40),YSPTS(40)

   IF(NTEM.EQ.1) THEN

   TDEP = YSPTS(NTEM)
```

```
      ELSEIF(TEMP.LE.TEMPROP(1)) THEN

        TDEP = YSPTS(1) + (TEMP-TEMPROP(1))/(TEMPROP(2)-TEMPROP(1))*
     >  (YSPTS(2)-YSPTS(1))

      ELSEIF(TEMP.GE.TEMPROP(NTEM)) THEN

        TDEP = YSPTS(NTEM-1) + (TEMP-TEMPROP(NTEM-1))/
     >  (TEMPROP(NTEM)-TEMPROP(NTEM-1))*(YSPTS(NTEM)-YSPTS(NTEM-1))

      ELSE

        DO I=2,NTEM

        IF(TEMP.LE.TEMPROP(I)) THEN
          TDEP = YSPTS(I-1) + (TEMP-TEMPROP(I-1))/
     >      (TEMPROP(I)-TEMPROP(I-1))*(YSPTS(I)-YSPTS(I-1))
            GO TO 1
        END IF

      END DO


      END IF

  1   RETURN

      END
C
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C    The subroutine VISC calculates and writes the stresses and
C  strains of a single load point for an elastic-viscoplastic
C  model.
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C

      SUBROUTINE VISC


      REAL NUF12(40), NUF23(40), NUM12(40), NUM23(40),NX(9999),NY(9999),
     >NXY(9999)

      COMMON/TYPEMOD/NA,NUMPLY,ZPOS(7),ANGLE(6)

      COMMON/MATERIAL/NUF12(40),NUF23(40),NUM12(40),NUM23(40),GM12(40),
     >EM22(40),EM11(40),AR,VF,GF12(40),EF22(40),EF11(40),HPRAMPTS(40),
     >YSPTS(40),TEMPROPF(40),TEMPROPM(40),NTEMF,NTEMM,HD,ALPHAF1(40),
     >ALPHAF2(40),ALPHAM1(40),ALPHAM2(40),OSAT(40),F1(40),F3(40),Z0(40),
```

```
     >BN(40),DNOT,Z0D(40),BND(40),BM1D(40),Z1D(40),R1D(40),
     >A1D(40),BM2D(40),Z2D(40),R2D(40),A2D(40),Z3D(40),TEMPREF,NTEMI,
     >SIC,TEMPROPI(40),SIFN1(40),UIFN1OA(40),SIFT1(40),UIFT1OA(40)

      COMMON/LOADING/NC1,NC2,NUMP,NUMCYC,DT(9999),TEMP(9999),NX(9999),
     >NY(9999),NXY(9999),M(9999)

      COMMON/ELASTPROP/SSF11(40),SSF22(40),SSF12(40),SSF23(40),
     >SSF44(40),SSM11(40),SSM22(40),SSM12(40),SSM23(40),SSM44(40),
     >A(6),B(6),C(6)

      COMMON/TOLERANCE/TOLP1,TOLP2,TOLP3,TOLV1,TOLV2,TOLV3,TOLV4

      REAL  LVEC1(50),LVEC0(50),DLVEC(50),ZI0(6,3),VI(50),VEPSMP0(6,12),
     >SMP0(6,3,4),SIF(6,2,2),SSI(6,2),SSIT(6,2),UIF(6,2,2),PPVEC(50),
     >FVEC(50),EPSEDOT(6,3,4),EPSEFFDE(6,3),DUIF(6,2,2),
     >RT(6,3),K2(6,3),ZI(6,3),BETA(6,3,4),OMEG(6,3,4),SM(6,3,4),
     >SMP(6,3,4),DSMP(6,3,4),SI(6,2,2),EPSEFFDP(6,3),EPSCALDP(6,3),
     >DEPSDP(6,3),DEPSMP(6,3,4),EPSMP(6,3,4),VEPSMP(6,12),UI(6,2,2),
     >EPSF(6,4),EPSM(6,3,4),SF(6,4),SPLY(6,3),SIGPLY(6,3),EPSC(3),
     >SIFN(3),UIFN(3),SIFT(3),UIFT(3),XVEC(50)

      COMMON/VISCOPLAST/H(50,50),HINV(50,50),T(6,3,3),TINT(6,3,3),
     >TH(50,20),BIGP(50,50),N,NCYC,TEM0,TIM0,PZI(6,3),LVEC0(50),
     >EPSMP0(6,3,4),SM0(6,3,4),UIF0(6,2,2),SI0(6,2,2),UI0(6,2,2),
     >K2(6,3),BETA0(6,3,4),OMEG0(6,3,4),EPSTHM1,EPSTHM2,EPSTHF1,
     >EPSTHF2,NDUMP

      COMMON/PMATRIX/PP(6,8,12),S11F,S12F,S22F,S23F,S44F,S11M,S12M,
     >S22M,S23M,S44M,SSI(6,2),SSIT(6,2)

      CHARACTER CHAR1*1

      FACT1 = 1.
C
C
C     load vector for desired point
C
C
      IF(NCYC.LT.2)  WRITE(6,*)'POINT ',N
          AM1 = TDEP(NTEMM,TEMPROPM,ALPHAM1,TEMP(N))
        AF1 = TDEP(NTEMF,TEMPROPF,ALPHAF1,TEMP(N))
        AM2 = TDEP(NTEMM,TEMPROPM,ALPHAM2,TEMP(N))
        AF2 = TDEP(NTEMF,TEMPROPF,ALPHAF2,TEMP(N))

      DO I=1,NUMPLY
          LVEC1(8*I-7) = AF1*(TEMP(N)-TEMPREF)-EPSTHF1
        LVEC1(8*I-6) = -(A(I)*AF2+B(I)*AM2)*(TEMP(N)-TEMPREF)+
     >       A(I)*EPSTHF2+B(I)*EPSTHM2
          LVEC1(8*I-5) = (AM1-AF1)*(TEMP(N)-TEMPREF)-(EPSTHM1-EPSTHF1)
          LVEC1(8*I-4) = A(I)*((AM2-AF2)*(TEMP(N)-TEMPREF) -
     >       (EPSTHM2-EPSTHF2))
          LVEC1(8*I-3) = A(I)*((AM2-AF2)*(TEMP(N)-TEMPREF) -
     >       (EPSTHM2-EPSTHF2))
```

```
      LVEC1(8*I-2) = TH(8*I-2,1)*NX(N)+TH(8*I-2,2)*NY(N)+
 >         TH(8*I-2,3)*NXY(N)
      LVEC1(8*I-1) = TH(8*I-1,1)*NX(N)+TH(8*I-1,2)*NY(N)+
 >         TH(8*I-1,3)*NXY(N)
      LVEC1(8*I) = TH(8*I,1)*NX(N)+TH(8*I,2)*NY(N)+
 >         TH(8*I,3)*NXY(N)
   END DO

    NR=3

    Z1D0=TDEP(NTEMM,TEMPROPM,Z1D,TEM0)
    Z2D0=TDEP(NTEMM,TEMPROPM,Z2D,TEM0)
    DO I=1,NUMPLY
      DO J=1,NR
        ZI0(I,J)=PZI(I,J)*(Z1D0-Z2D0)+Z2D0
    END DO
    END DO

C  Initialize interface load vector
    MATSIZ=8*NUMPLY
    DO I=1,MATSIZ
      VI(I)=0.
    END DO



     DTEM = (TEMP(N)-TEM0)/M(N)
     DTIM = DT(N)/M(N)

     MM=1
     DO J=1,MATSIZ
         DLVEC(J)=(LVEC1(J)-LVEC0(J))/M(N)
     END DO

   DO I=1,NUMPLY
     DO J=1,NR
         VEPSMP0(I,J)=EPSMP0(I,J,4)
       VEPSMP0(I,3*J+1)=EPSMP0(I,J,1)
       VEPSMP0(I,3*J+2)=EPSMP0(I,J,2)
       VEPSMP0(I,3*J+3)=EPSMP0(I,J,3)
   END DO
   END DO

   DO I=1,NUMPLY
     DO J=1,NR
       HYDRO = (SM0(I,J,1)+SM0(I,J,2)+SM0(I,J,3))/3.
     SMP0(I,J,1)=SM0(I,J,1)-HYDRO
     SMP0(I,J,2)=SM0(I,J,2)-HYDRO
     SMP0(I,J,3)=SM0(I,J,3)-HYDRO
     SMP0(I,J,4)=SM0(I,J,4)
   END DO
   END DO

C
```

```
C
C     Enter the matrix BIGP and Pplast
C
C
  1    TEM1=TEM0+DTEM

C  First determine temperature dependent properties required to find
C  the BIGP matrix

       S11F = TDEP(NTEMF,TEMPROPF,SSF11,TEM1)
       S12F = TDEP(NTEMF,TEMPROPF,SSF12,TEM1)
       S22F = TDEP(NTEMF,TEMPROPF,SSF22,TEM1)
       S23F = TDEP(NTEMF,TEMPROPF,SSF23,TEM1)
       S44F = TDEP(NTEMF,TEMPROPF,SSF44,TEM1)

       S11M = TDEP(NTEMM,TEMPROPM,SSM11,TEM1)
       S12M = TDEP(NTEMM,TEMPROPM,SSM12,TEM1)
       S22M = TDEP(NTEMM,TEMPROPM,SSM22,TEM1)
       S23M = TDEP(NTEMM,TEMPROPM,SSM23,TEM1)
       S44M = TDEP(NTEMM,TEMPROPM,SSM44,TEM1)

       SIFN(1)  = TDEP(NTEMI,TEMPROPI,SIFN1,TEM1)
       UIFN(1)  = 0.
       SIFN(2)  = 0.
       UIFN(2)  = TDEP(NTEMI,TEMPROPI,UIFN1OA,TEM1)
       SIFN(3)  = 0.
       UIFN(3)  = UIFN(2)+0.05

       SIFT(1)  = TDEP(NTEMI,TEMPROPI,SIFT1,TEM1)
       UIFT(1)  = 0.
       SIFT(2)  = 0.5
       UIFT(2)  = TDEP(NTEMI,TEMPROPI,UIFT1OA,TEM1)
       SIFT(3)  = 0.5
       UIFT(3)  = UIFT(2)+0.05

C  Determine stress point where interfacial failure begins.

       DO I=1,NUMPLY
         DO K=1,2
            SIF(I,K,1)  = TDEP(3,UIFN,SIFN,UIF0(I,K,1))
            SIF(I,K,2)  = TDEP(3,UIFT,SIFT,UIF0(I,K,2))
           IF(SI0(I,K,1).LE.SIC.OR.UI0(I,K,1).LT.0.) THEN
             SSI(I,K)  = 0.
           ELSE
             SSI(I,K)=UIF0(I,K,1)/(SIF(I,K,1)-SIC)
           END IF
           SSIT(I,K)=UIF0(I,K,2)/SIF(I,K,2)
C
C  Initialize interfacial failure displacement
C
         DO J=1,2
         UIF(I,K,J)=UIF0(I,K,J)
         END DO
         END DO
```

```
      END DO

C
C  Find the BIGP and PP matrices

      CALL BIGPMAT
      CALL BIGPPMAT

      ITER=1
C
C    Multiply Pplast by the accumulated plastic strain for each ply,
C  and determine the plastic component of the forcing vector.
C
      DO J=1,MATSIZ
        PPVEC(J)=0.
      END DO

      DO I=1,NUMPLY

      DO J=1,8

        DO K=1,12

          PPVEC(8*I-(8-J)) = PPVEC(8*I-(8-J)) + PP(I,J,K)*
     >                         VEPSMP0(I,K)

        END DO

      END DO

      END DO

C
C    Add up the complete forcing vector.
C
      DO I=1,NUMPLY
        VI(8*I-6)=A(I)*SSI(I,1)*SIC
      VI(8*I-4)=A(I)*SSI(I,1)*SIC
      VI(8*I-3)=A(I)*SSI(I,2)*SIC
      END DO

      DO I=1,MATSIZ
        FVEC(I) = DLVEC(I)+LVEC0(I)-PPVEC(I)+VI(I)
      END DO

C
C   Solve by matrix inversion for coupled stress terms
C

      CALL GAUSS(MATSIZ,BIGP,FVEC,XVEC)
C
C
C    Stresses in matrix and interface regions for elastic response.
C
```

```
C
      CALL STRESS(NUMPLY,EPSMP0,XVEC,TINT,A,B,C,SM,SF,SI,SPLY,
     >SSIT,S44F,S11M,S12M,S44M)


C
C   Elastic strain rate if step is completely elastic response.
C

      DO I=1,NUMPLY
       DO J=1,NR
        V1=SM(I,J,1)-SM0(I,J,1)
      V2=SM(I,J,2)-SM0(I,J,2)
        V3=SM(I,J,3)-SM0(I,J,3)
      V4=SM(I,J,4)-SM0(I,J,4)
        EPSEDOT(I,J,1) = (S11M*V1+S12M*V2+S12M*V3)/DTIM
      EPSEDOT(I,J,2) = (S12M*V1+S22M*V2+S23M*V3)/DTIM
      EPSEDOT(I,J,3) = (S12M*V1+S23M*V2+S22M*V3)/DTIM
      EPSEDOT(I,J,4) = S44M*V4/DTIM
      EPSEFFDE(I,J) = SQRT(2./3.*(EPSEDOT(I,J,1)**2+
     >  EPSEDOT(I,J,2)**2+EPSEDOT(I,J,3)**2+0.5*(EPSEDOT(I,J,4)**2)))
       END DO
      END DO

C
C   Set initial effective plastic strain rate for the step to zero
C
      DO I=1,NUMPLY
        DO J=1,NR
          EPSEFFDP(I,J) = 0
      END DO
      END DO
C
C   Set the initial interface failure displacement increment to zero
C
      DO I=1,NUMPLY
        DO J=1,2
        DO K=1,2
          DUIF(I,J,K) = 0.0
        END DO
      END DO
      END DO

C
C   Find temperature dependent constants for the type of viscoplastic
C   analysis chosen
C

C  Bodner-Partom with back stress

C       FS3=TDEP(NTEMM,TEMPROPM,F3,TEM1)
C       FS1=TDEP(NTEMM,TEMPROPM,F1,TEM1)
C       OMEGSAT = TDEP(NTEMM,TEMPROPM,OSAT,TEM1)
C       Z=TDEP(NTEMM,TEMPROPM,Z0,TEM1)
```

```
C      EN = TDEP(NTEMM,TEMPROPM,BN,TEM1)

C  Bodner-Partom with directional hardening

       BND1=TDEP(NTEMM,TEMPROPM,BND,TEM1)
       BM1D1=TDEP(NTEMM,TEMPROPM,BM1D,TEM1)
       Z1D1=TDEP(NTEMM,TEMPROPM,Z1D,TEM1)
       R1D1=TDEP(NTEMM,TEMPROPM,R1D,TEM1)
       A1D1=TDEP(NTEMM,TEMPROPM,A1D,TEM1)
       BM2D1=TDEP(NTEMM,TEMPROPM,BM2D,TEM1)
       Z2D1=TDEP(NTEMM,TEMPROPM,Z2D,TEM1)
       R2D1=TDEP(NTEMM,TEMPROPM,R2D,TEM1)
       A2D1=TDEP(NTEMM,TEMPROPM,A2D,TEM1)
       Z3D1=TDEP(NTEMM,TEMPROPM,Z3D,TEM1)

       DZ1DT = TDEP(NTEMM,TEMPROPM,Z1D,(TEM1+1.))-Z1D1
       DZ2DT = TDEP(NTEMM,TEMPROPM,Z2D,(TEM1+1.))-Z2D1
       DZ3DT = TDEP(NTEMM,TEMPROPM,Z3D,(TEM1+1.))-Z3D1
       TDOT = DTEM/DTIM
C
C
C   Bodner-Partom with isotropic hardening only.
C
C
C      PNA1=TDEP(NTEMM,TEMPROPM,BND,TEM1)
C      PMA1=TDEP(NTEMM,TEMPROPM,BM1D,TEM1)
C      Z1D1=TDEP(NTEMM,TEMPROPM,Z1D,TEM1)
C      Z2D1=TDEP(NTEMM,TEMPROPM,Z2D,TEM1)
C
C
C
      DO I=1,NUMPLY
        DO J=1,NR
          RT(I,J) = SQRT(3.*K2(I,J))
        ZI(I,J) = PZI(I,J)*(Z1D1-Z2D1)+Z2D1
        DO K=1,4
          BETA(I,J,K) = BETA0(I,J,K)
          OMEG(I,J,K) = OMEG0(I,J,K)
        END DO
      END DO
      END DO
C
C   Begin iteration
C

C
C   Calculate the deviatoric stress and change in deviatoric stress
C   from the previous step.
C

   2  DO I=1,NUMPLY
       DO J=1,NR
        HYDRO = (SM(I,J,1)+SM(I,J,2)+SM(I,J,3))/3.
      SMP(I,J,1)=SM(I,J,1)-HYDRO
```

```
      SMP(I,J,2)=SM(I,J,2)-HYDRO
      SMP(I,J,3)=SM(I,J,3)-HYDRO
      SMP(I,J,4)=SM(I,J,4)
      DO K=1,4
        DSMP(I,J,K)=SMP(I,J,K)-SMP0(I,J,K)
      END DO
       END DO
      END DO
C
C  Call the appropriate analysis method
C

C  Bodner-Partom with back stress

C     CALL BODBAK(FS1,FS3,OMEGSAT,EN,Z,DTIM,RT,DSMP,EPSEFFDP,SMP,
C    >OMEG,EPSCALDP)

C  Bodner-Partom with directional hardening

      CALL BODDIR(Z0D1,BND1,BM1D1,Z1D1,R1D1,A1D1,BM2D1,Z2D1,R2D1,
     >A2D1,Z3D1,DZ1DT,DZ2DT,DZ3DT,DNOT,TDOT,DTIM,SMP,SM,RT,EPSEFFDP,
     >BETA,BETA0,ZI,ZI0,EPSCALDP)
C
C  Bodner-Partom with isotropic hardening only

C     CALL BODISO(Z2D1,PNA1,PMA1,Z1D1,DNOT,DTIM,SMP,SM,RT,
C    >ZI,ZI0,EPSEFFDP,EPSCALDP)
C
C
C    If load increment is too great, split it in half.
C
C
      IF(ITER.EQ.1) THEN
        DO I=1,NUMPLY
        DO J=1,2
          IF(SI(I,J,1).GT.(SIF(I,J,1)+TOLV4)) GO TO 7
          IF(ABS(SI(I,J,2)).GT.ABS(SIF(I,J,2)+TOLV4)) GO TO 7
        END DO
          DO J=1,NR
          IF(EPSCALDP(I,J)/TOLV1.GT.EPSEFFDE(I,J)) THEN
            IF(EPSEFFDE(I,J).LT.1.0E-06) THEN
              DO II=1,NUMPLY
                DO JJ=1,NR
                  EPSEFFDE(II,JJ) = 1.0E-06
              END DO
              END DO
              GO TO 8
            END IF

  7         M(N)=2*M(N)-MM+1
              IF(M(N).GT.1000) THEN
              WRITE(6,*)'MAXIMUM Subincrements Exceeded'
              WRITE(6,*)'Last incrementing ratio = ',
     >EPSCALDP(I,J)/EPSEFFDE(I,J)
```

```
               READ(5,*)
           NDUMP = 1
           RETURN
             END IF
           DTEM=DTEM/2.
           DTIM=DTIM/2.
           DO JJ=1,MATSIZ
             DLVEC(JJ)=DLVEC(JJ)/2.
           END DO
           GO TO 1
           END IF
       END DO

     END DO

     END IF

C
C    Find new effective plastic strain rate and change in plastic
C    strain based on the calculation.
C

  8  DO I=1,NUMPLY
      DO J=1,NR
       DEPSDP(I,J) = EPSCALDP(I,J)-EPSEFFDP(I,J)

       IF(DEPSDP(I,J).GT.0.) THEN
         RATIO = DEPSDP(I,J)/(DEPSDP(I,J)+TOLV2*EPSEFFDE(I,J))
       ELSEIF(DEPSDP(I,J).LT.0.) THEN
         RATIO = -DEPSDP(I,J)/(DEPSDP(I,J)-TOLV2*EPSEFFDE(I,J))
       ELSE
         RATIO = 0.
       END IF
       EPSEFFDP(I,J)=EPSEFFDP(I,J)+RATIO*EPSEFFDE(I,J)

     IF(RT(I,J).EQ.0.0) THEN
     DO K=1,4
       DEPSMP(I,J,K)=0.0
     END DO
     ELSE
     DO K=1,4
         DEPSMP(I,J,K)=DTIM*1.5*EPSEFFDP(I,J)*(SMP(I,J,K)-
    >    OMEG(I,J,K))/RT(I,J)
     END DO
     END IF
     DEPSMP(I,J,4)=2*DEPSMP(I,J,4)
      END DO

      DO J=1,2
       IF(SI(I,J,1).LE.SIF(I,J,1).AND.DUIF(I,J,1).EQ.0.0) THEN
         DUIF(I,J,1)=0.0
       ELSE
         DUIF(I,J,1)=FACT1*SSI(I,J)*(SI(I,J,1)-SIF(I,J,1))
       END IF
```

```
        IF(ABS(SI(I,J,2)).LE.ABS(SIF(I,J,2)).AND.DUIF(I,J,
     >                                             2).EQ.0.0) THEN
          DUIF(I,J,2)=0.0
        ELSE
            DUIF(I,J,2)=FACT1*SSIT(I,J)*(ABS(SI(I,J,2))-
     >                                            ABS(SIF(I,J,2)))
        END IF
        DO K=1,2
          UIF(I,J,K)=UIF(I,J,K)+DUIF(I,J,K)
        END DO
      END DO
      END DO

C
C    Calculate new matrix stresses for this iteration
C
      DO I=1,NUMPLY
        DO J=1,NR
       DO K=1,4
        EPSMP(I,J,K) = DEPSMP(I,J,K)+EPSMP0(I,J,K)
       END DO
         VEPSMP(I,J)=EPSMP(I,J,4)
       VEPSMP(I,3*J+1)=EPSMP(I,J,1)
       VEPSMP(I,3*J+2)=EPSMP(I,J,2)
       VEPSMP(I,3*J+3)=EPSMP(I,J,3)
        END DO
      END DO

C   Determine stress point where interfacial failure begins.

      DO I=1,NUMPLY
        DO J=1,2
         SIF(I,J,1) = TDEP(3,UIFN,SIFN,UIF(I,J,1))
         SIF(I,J,2) = TDEP(3,UIFT,SIFT,UIF(I,J,2))
         UI(I,J,1)=SSI(I,J)*(SI(I,J,1)-SIC)
       UI(I,J,2)=SSIT(I,J)*SI(I,J,2)
         IF(SI(I,J,1).LE.SIC.OR.UI(I,J,1).LT.0.) THEN
           SSI(I,J) = 0.
         ELSE
           SSI(I,J)=UIF(I,J,1)/(SIF(I,J,1)-SIC)
         END IF
          SSIT(I,J)=UIF(I,J,2)/SIF(I,J,2)
        END DO
      END DO

      CALL BIGPMAT
      CALL BIGPPMAT

C
C     Multiply Pplast by the accumulated plastic strain for each ply,
C   and determine the plastic component of the forcing vector.
C
      DO J=1,MATSIZ
        PPVEC(J)=0.
```

```
      END DO

      DO I=1,NUMPLY

      DO J=1,8

        DO K=1,12

          PPVEC(8*I-(8-J)) = PPVEC(8*I-(8-J)) + PP(I,J,K)*
     >                          VEPSMP(I,K)

        END DO

      END DO

      END DO

C
C     Add up the complete forcing vector.
C
      DO I=1,NUMPLY
        VI(8*I-6)=A(I)*SSI(I,1)*SIC
      VI(8*I-4)=A(I)*SSI(I,1)*SIC
      VI(8*I-3)=A(I)*SSI(I,2)*SIC
      END DO

      DO I=1,MATSIZ
        FVEC(I) = DLVEC(I)+LVEC0(I)-PPVEC(I)+VI(I)
      END DO


C
C    Solve by matrix inversion for coupled stress terms
C

      CALL GAUSS(MATSIZ,BIGP,FVEC,XVEC)

C
C
C     Stresses in matrix regions
C
C

        CALL STRESS(NUMPLY,EPSMP,XVEC,TINT,A,B,C,SM,SF,SI,SPLY,
     >SSIT,S44F,S11M,S12M,S44M)

C
C    Is iteration complete?
C
      IF(ITER.GT.3000) THEN


              WRITE(6,1090) N,NCYC
 1090 FORMAT('     * * * ERROR * * *',/,' Maximum iterations exceeded',
```

```
     >' while attempting to calculate',/,' load point',I3,' in ',
     >'loading cycle',I7)
            WRITE(6,*)'M = ',M(N)
          WRITE(6,*)'SUBINCREMENT POINT FURTHER?'
          READ(5,*) CHAR1
          IF(CHAR1.EQ.'Y'.OR.CHAR1.EQ.'y') GO TO 7
             NDUMP = 1
             RETURN
      ELSE

        DO I=1,NUMPLY
        DO J=1,2
          DO K=1,2
           IF(ABS(DUIF(I,J,K)).GT.TOLV3*UIF(I,J,K)) THEN
             ITER=ITER+1
             GO TO 2
           END IF
          END DO
        END DO

        DO J=1,NR
          IF(ABS(DEPSDP(I,J)).GT.ABS(TOLV3*EPSEFFDE(I,J))) THEN
            ITER=ITER+1
            GO TO 2
          END IF
        END DO
      END DO

      END IF


C
C
C     Calculate the strains for this increment from the stress-strain
C     relations.
C
C
      DO I=1,NUMPLY
        EPSF(I,1) = S11F*SF(I,1)+S12F*SF(I,2)+S12F*SF(I,3)+
     >    AF1*(TEM1-TEMPREF) - EPSTHF1
        EPSF(I,2) = S12F*SF(I,1)+S22F*SF(I,2)+S23F*SF(I,3)+
     >    AF2*(TEM1-TEMPREF) - EPSTHF2
        EPSF(I,3) = S12F*SF(I,1)+S23F*SF(I,2)+S22F*SF(I,3)+
     >    AF2*(TEM1-TEMPREF) - EPSTHF2
        EPSF(I,4) = S44F*SF(I,4)
        DO J=1,NR
          EPSM(I,J,1) = S11M*SM(I,J,1)+S12M*SM(I,J,2)+S12M*SM(I,J,3)+
     >                AM1*(TEM1-TEMPREF)-EPSTHM1+EPSMP(I,J,1)
          EPSM(I,J,2) = S12M*SM(I,J,1)+S22M*SM(I,J,2)+S23M*SM(I,J,3)+
     >                AM2*(TEM1-TEMPREF)-EPSTHM2+EPSMP(I,J,2)
          EPSM(I,J,3) = S12M*SM(I,J,1)+S23M*SM(I,J,2)+S22M*SM(I,J,3)+
     >                AM2*(TEM1-TEMPREF)-EPSTHM2+EPSMP(I,J,3)
          EPSM(I,J,4) = S44M*SM(I,J,4)+EPSMP(I,J,4)
      END DO
```

```
      UI(I,1,2) = SSIT(I,1)*SI(I,1,2)
      UI(I,2,2) = SSIT(I,2)*SI(I,2,2)
    UI(I,1,1) = SSI(I,1)*(SI(I,1,1)-SIC)
    UI(I,2,1) = SSI(I,2)*(SI(I,2,1)-SIC)
    END DO


C
C     Ply stresses
C
    DO I=1,NUMPLY

      SPLY(I,1)=(A(I)**2.*SF(I,1)+A(I)*B(I)*SM(I,1,1)+B(I)*C(I)
   >      *SM(I,2,1)+A(I)*C(I)*SM(I,3,1))/((A(I)+B(I))*(A(I)+C(I)))
      SPLY(I,2)=(A(I)*SM(I,1,2)+C(I)*SM(I,2,2))/(A(I)+C(I))

    END DO

    DO I=1,NUMPLY

    SIGPLY(I,1)=TINT(I,1,1)*SPLY(I,1)+TINT(I,2,1)*SPLY(I,2)+
   >        TINT(I,3,1)*SPLY(I,3)
    SIGPLY(I,2)=TINT(I,1,2)*SPLY(I,1)+TINT(I,2,2)*SPLY(I,2)+
   >        TINT(I,3,2)*SPLY(I,3)
    SIGPLY(I,3)=TINT(I,1,3)*SPLY(I,1)+TINT(I,2,3)*SPLY(I,2)+
   >        TINT(I,3,3)*SPLY(I,3)

    END DO

      DO I=1,3
      EPSC(I)=XVEC(I)
    END DO


C
C     Time
C
    TIM1=DTIM+TIM0
C
C     Set values for next increment
C
    DO I=1,NUMPLY
      DO J=1,NR
      DO K=1,4
        SM0(I,J,K)=SM(I,J,K)
        SMP0(I,J,K)=SMP(I,J,K)
        EPSMP0(I,J,K)=EPSMP(I,J,K)
        OMEG0(I,J,K)=OMEG(I,J,K)
        BETA0(I,J,K)=BETA(I,J,K)
      END DO
      PZI(I,J)=(ZI(I,J)-Z2D1)/(Z1D1-Z2D1)
      ZI0(I,J)=ZI(I,J)
    END DO
```

```
      END DO
      DO I=1,NUMPLY
        DO J=1,2
        DO K=1,2
          SI0(I,J,K)=SI(I,J,K)
          UI0(I,J,K)=UI(I,J,K)
          UIF0(I,J,K)=UIF(I,J,K)
        END DO
          PUIF1=UIF(I,J,1)/UIFN(2)
          PUIF2=UIF(I,J,2)/UIFT(2)
          IF(PUIF1.GT.PUIF2) THEN
            UIF0(I,J,2)=PUIF1*UIFT(2)
            UIF0(I,J,1)=UIF(I,J,1)
          ELSE
            UIF0(I,J,1)=PUIF2*UIFN(2)+0.0000001
            UIF0(I,J,2)=UIF(I,J,2)
          END IF
      END DO
      END DO
      DO I=1,MATSIZ
        LVEC0(I)=DLVEC(I)+LVEC0(I)
      END DO
      TEM0=TEM1
      TIM0=TIM1

C
C   Check if desired load point has been achieved.
C

        IF(MM.LT.M(N)) THEN
          MM = MM+1
          GO TO 1
        END IF


C
C
C  Write to scratch file
C
C
      SCX=NX(N)/(ZPOS(NUMPLY+1)-ZPOS(1))
      SCY=NY(N)/(ZPOS(NUMPLY+1)-ZPOS(1))
      SCXY=NXY(N)/(ZPOS(NUMPLY+1)-ZPOS(1))

      WRITE(8) TIM1,TEM1,(EPSC(K),K=1,3),SCX,SCY,SCXY,
     >((SIGPLY(I,K),K=1,3),(EPSF(I,K),SF(I,K),K=1,4),((EPSM(I,J,K),
     >SM(I,J,K),K=1,4),J=1,NR),((UI(I,J,K),SI(I,J,K),K=1,2),J=1,2),
     >I=1,NUMPLY)


C
C
C     Save present load vector as initial point for subsequent load.
C
```

```
C
          DO I=1,MATSIZ
          LVEC0(I)=LVEC1(I)
        END DO
        TEM0=TEMP(N)

          RETURN

        END
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C    The subroutine WRITEDAT is for writing solution sets from the
C  FTS method to formatted or unformatted files for either printing
C  or saving for future analysis.
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *


      SUBROUTINE WRITEDAT



      REAL NUF12(40), NUF23(40), NUM12(40), NUM23(40)

      CHARACTER FIB*1,MATE*1,MATP*1,MATV*1,TCHARP*1,TCHARV*1,
     >COMP*40, ECHAR*1, LCHAR*1

      COMMON/TYPEMOD/NA,NUMPLY,ZPOS(7),ANGLE(6)

      COMMON/MATERIAL/NUF12(40),NUF23(40),NUM12(40),NUM23(40),GM12(40),
     >EM22(40),EM11(40),AR,VF,GF12(40),EF22(40),EF11(40),HPRAMPTS(40),
     >YSPTS(40),TEMPROPF(40),TEMPROPM(40),NTEMF,NTEMM,HD,ALPHAF1(40),
     >ALPHAF2(40),ALPHAM1(40),ALPHAM2(40),OSAT(40),F1(40),F3(40),Z0(40),
     >BN(40),DNOT,Z0D(40),BND(40),BM1D(40),Z1D(40),R1D(40),
     >A1D(40),BM2D(40),Z2D(40),R2D(40),A2D(40),Z3D(40),TEMPREF,NTEMI,
     >SIC,TEMPROPI(40),SIFN1(40),UIFN1OA(40),SIFT1(40),UIFT1OA(40)

      COMMON/LOADING/NC1,NC2,NUMP,NUMCYC,DT(9999),TEMP(9999),NX(9999),
     >NY(9999),NXY(9999),M(9999)

      COMMON/ELASTPROP/SSF11(40),SSF22(40),SSF12(40),SSF23(40),
     >SSF44(40),SSM11(40),SSM22(40),SSM12(40),SSM23(40),SSM44(40),
     >A(6),B(6),C(6)

      COMMON/TOLERANCE/TOLP1,TOLP2,TOLP3,TOLV1,TOLV2,TOLV3,TOLV4

      COMMON/WORDS/FIB,MATE,MATP,MATV,TCHARP,TCHARV,COMP,ECHAR,LCHAR

      REAL  NX(9999),NY(9999),NXY(9999),EPSCOM(3),SIGPLY(6,3),EPSF(6,4),
     >SF(6,4),EPSM(6,3,4),SM(6,3,4),UI(6,2,2),SI(6,2,2)

      CHARACTER OUTDAT*15,CYCSYM(99)*1
```

```
 3   REWIND 8

       WRITE(6,*)
       WRITE(6,*)
       WRITE(6,*)
       WRITE(6,*)
       WRITE(6,*)
       WRITE(6,*)
       WRITE(6,*)
       WRITE(6,*)
           WRITE(6,*) '   * * * * * * * * * * * * * * * * * '
           WRITE(6,*) '   *     Write Out Results        * '
           WRITE(6,*) '   * * * * * * * * * * * * * * * * * '
           WRITE(6,*)
           WRITE(6,*)
           WRITE(6,*) '     (1) Unformatted file '
           WRITE(6,*) '     (2) Global ASCII file '
     WRITE(6,*) '     **N/A**(3) Formatted file for printing '
           WRITE(6,*) '     (4) Return to results menu '
     WRITE(6,*)
     WRITE(6,*)
     WRITE(6,*) '  Enter Selection:  '
       READ(5,*) NW


     IF(NW.EQ.1) THEN
         IF(LCHAR.EQ.'N') THEN
         WRITE(6,101)
101  FORMAT(/,' No solution set exists in the program database.')
           READ(5,*)
         GO TO 3
       END IF


      WRITE(6,*)' Enter name of the unformatted file to be created.'
       READ(5,201) OUTDAT
201  FORMAT(A15)
         OPEN(30,FILE=OUTDAT,STATUS='NEW',FORM='UNFORMATTED')

       WRITE(30) NA,NUMPLY,NTEMF,NTEMM,NTEMI,AR,VF,HD,DNOT,SIC
    >        TEMPREF,NC1,NC2,NUMP,NUMCYC,FIB,MATE,MATP,MATV,TCHARP,
    >        TCHARV,COMP,ECHAR,LCHAR

         WRITE(30)  (ZPOS(I),I=1,NUMPLY+1),(ANGLE(J),J=1,NUMPLY)

         WRITE(30)  (TEMPROPF(I),NUF12(I),NUF23(I),GF12(I),EF22(I),
    >               EF11(I),ALPHAF1(I),ALPHAF2(I),I=1,NTEMF)
         WRITE(30)  (TEMPROPM(I),NUM12(I),NUM23(I),GM12(I),EM22(I),
    >               EM11(I),ALPHAM1(I),ALPHAM2(I),HPRAMPTS(I),YSPTS(I),
    >               OSAT(I),F1(I),F3(I),Z0(I),BN(I),Z0D(I),BND(I),
    >               BM1D(I),Z1D(I),R1D(I),A1D(I),BM2D(I),Z2D(I),
    >               R2D(I),A2D(I),Z3D(I),I=1,NTEMM)
```

```
      WRITE(30) (TEMPROPI(I),SIFN1(I),UIFN1OA(I),
>                SIFT1(I),UIFT1OA(I),I=1,NTEMI)

    DO I=1,NUMP
      WRITE(30) DT(I),TEMP(I),NX(I),NY(I),NXY(I),M(I)
    END DO


        DO N=1,NC1-1
         READ(8) TIM1,TEM1,(EPSCOM(K),K=1,3),PNX,PNY,PNXY,
>((SIGPLY(I,K),K=1,3),(EPSF(I,K),SF(I,K),K=1,4),((EPSM(I,J,K),
>SM(I,J,K),K=1,4),J=1,3),((UI(I,J,K),SI(I,J,K),K=1,2),J=1,2),
>I=1,NUMPLY)

        WRITE(30) TIM1,TEM1,(EPSCOM(K),K=1,3),PNX,PNY,PNXY,
>((SIGPLY(I,K),K=1,3),(EPSF(I,K),SF(I,K),K=1,4),((EPSM(I,J,K),
>SM(I,J,K),K=1,4),J=1,3),((UI(I,J,K),SI(I,J,K),K=1,2),J=1,2),
>I=1,NUMPLY)

        END DO

      DO NCYC=1,NUMCYC

        DO N=NC1,NC2
         READ(8) TIM1,TEM1,(EPSCOM(K),K=1,3),PNX,PNY,PNXY,
>((SIGPLY(I,K),K=1,3),(EPSF(I,K),SF(I,K),K=1,4),((EPSM(I,J,K),
>SM(I,J,K),K=1,4),J=1,3),((UI(I,J,K),SI(I,J,K),K=1,2),J=1,2),
>I=1,NUMPLY)

        WRITE(30) TIM1,TEM1,(EPSCOM(K),K=1,3),PNX,PNY,PNXY,
>((SIGPLY(I,K),K=1,3),(EPSF(I,K),SF(I,K),K=1,4),((EPSM(I,J,K),
>SM(I,J,K),K=1,4),J=1,3),((UI(I,J,K),SI(I,J,K),K=1,2),J=1,2),
>I=1,NUMPLY)

        END DO

      END DO

      DO N=NC2+1,NUMP
         READ(8) TIM1,TEM1,(EPSCOM(K),K=1,3),PNX,PNY,PNXY,
>((SIGPLY(I,K),K=1,3),(EPSF(I,K),SF(I,K),K=1,4),((EPSM(I,J,K),
>SM(I,J,K),K=1,4),J=1,3),((UI(I,J,K),SI(I,J,K),K=1,2),J=1,2),
>I=1,NUMPLY)

        WRITE(30) TIM1,TEM1,(EPSCOM(K),K=1,3),PNX,PNY,PNXY,
>((SIGPLY(I,K),K=1,3),(EPSF(I,K),SF(I,K),K=1,4),((EPSM(I,J,K),
>SM(I,J,K),K=1,4),J=1,3),((UI(I,J,K),SI(I,J,K),K=1,2),J=1,2),
>I=1,NUMPLY)

        END DO

    CLOSE(30)

  ELSEIF(NW.EQ.2) THEN
```

```
      IF(LCHAR.EQ.'N') THEN
      WRITE(6,101)
        READ(5,*)
      GO TO 3
    END IF


   WRITE(6,*)' Enter name of the global ASCII file to be created.'
    READ(5,201) OUTDAT
      OPEN(30,FILE=OUTDAT,STATUS='NEW')

    WRITE(30,*) NA,NUMPLY,NTEMF,NTEMM,NTEMI,AR,VF,HD,DNOT,SIC
>        TEMPREF,NC1,NC2,NUMP,NUMCYC


    WRITE(30,1000) FIB,MATE,MATP,MATV,TCHARP,TCHARV,ECHAR,
>                    LCHAR,COMP

1000 FORMAT(8A1,A40)

      WRITE(30,*) (ZPOS(I),I=1,NUMPLY+1),(ANGLE(J),J=1,NUMPLY)


      DO I=1,NTEMF
      WRITE(30,*) TEMPROPF(I),NUF12(I),NUF23(I),GF12(I),EF22(I),
>               EF11(I),ALPHAF1(I),ALPHAF2(I)
      END DO

    DO I=1,NTEMM
      WRITE(30,*) TEMPROPM(I),NUM12(I),NUM23(I),GM12(I),EM22(I),
>              EM11(I),ALPHAM1(I),ALPHAM2(I),HPRAMPTS(I),YSPTS(I),
>              OSAT(I),F1(I),F3(I),Z0(I),BN(I),Z0D(I),BND(I),
>              BM1D(I),Z1D(I),R1D(I),A1D(I),BM2D(I),Z2D(I),
>              R2D(I),A2D(I),Z3D(I)
    END DO

    DO I=1,NTEMI
    WRITE(30,*) TEMPROPI(I),SIFN1(I),UIFN10A(I),
>              SIFT1(I),UIFT10A(I)
      END DO


    DO I=1,NUMP
      WRITE(30,*) DT(I),TEMP(I),NX(I),NY(I),NXY(I),M(I)
    END DO

        DO N=1,NC1-1
         READ(8) TIM1,TEM1,(EPSCOM(K),K=1,3),PNX,PNY,PNXY,
>((SIGPLY(I,K),K=1,3),(EPSF(I,K),SF(I,K),K=1,4),((EPSM(I,J,K),
>SM(I,J,K),K=1,4),J=1,3),((UI(I,J,K),SI(I,J,K),K=1,2),J=1,2),
>I=1,NUMPLY)

         WRITE(30,*) TIM1,TEM1,(EPSCOM(K),K=1,3),PNX,PNY,PNXY,
```

```
>((SIGPLY(I,K),K=1,3),(EPSF(I,K),SF(I,K),K=1,4),((EPSM(I,J,K),
>SM(I,J,K),K=1,4),J=1,3),((UI(I,J,K),SI(I,J,K),K=1,2),J=1,2),
>I=1,NUMPLY)

       END DO

     DO NCYC=1,NUMCYC

       DO N=NC1,NC2
        READ(8) TIM1,TEM1,(EPSCOM(K),K=1,3),PNX,PNY,PNXY,
>((SIGPLY(I,K),K=1,3),(EPSF(I,K),SF(I,K),K=1,4),((EPSM(I,J,K),
>SM(I,J,K),K=1,4),J=1,3),((UI(I,J,K),SI(I,J,K),K=1,2),J=1,2),
>I=1,NUMPLY)

        WRITE(30,*) TIM1,TEM1,(EPSCOM(K),K=1,3),PNX,PNY,PNXY,
>((SIGPLY(I,K),K=1,3),(EPSF(I,K),SF(I,K),K=1,4),((EPSM(I,J,K),
>SM(I,J,K),K=1,4),J=1,3),((UI(I,J,K),SI(I,J,K),K=1,2),J=1,2),
>I=1,NUMPLY)
       END DO

     END DO

     DO N=NC2+1,NUMP
        READ(8) TIM1,TEM1,(EPSCOM(K),K=1,3),PNX,PNY,PNXY,
>((SIGPLY(I,K),K=1,3),(EPSF(I,K),SF(I,K),K=1,4),((EPSM(I,J,K),
>SM(I,J,K),K=1,4),J=1,3),((UI(I,J,K),SI(I,J,K),K=1,2),J=1,2),
>I=1,NUMPLY)

        WRITE(30,*) TIM1,TEM1,(EPSCOM(K),K=1,3),PNX,PNY,PNXY,
>((SIGPLY(I,K),K=1,3),(EPSF(I,K),SF(I,K),K=1,4),((EPSM(I,J,K),
>SM(I,J,K),K=1,4),J=1,3),((UI(I,J,K),SI(I,J,K),K=1,2),J=1,2),
>I=1,NUMPLY)
       END DO

   CLOSE(30)

 ELSEIF(NW.EQ.3) THEN
     IF(LCHAR.EQ.'N') THEN
     WRITE(6,101)
       READ(5,*)
     GO TO 3
   END IF


   ELSEIF(NW.EQ.4) THEN

   RETURN


 END IF

 GO TO 3

 END
```

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13. ABSTRACT *(Maximum 200 words)*

The program described in this document (LISOL) is for analyzing the thermal and inelastic behavior of continuous fiber-reinforced laminated composites with symmetric layups. Its main application has been in the area of metal matrix composites (MMCs). In particular, titanium-based MMCs have been extensively analyzed using LISOL. The program is very adept at performing thermomechanical cyclic loading.

Inelastic material behavior is modeled using the Bodner-Partom viscoplastic theory, and the interface between fiber and matrix may be modeled with a progressive failure scheme. These nonlinearities as well as the thermal and elastic properties of the constituents are combined through a micromechanics approach which assumes an average representative volume element for a single ply. The equations for a single ply are then assembled for the entire layup through the classical laminated plate theory.

LISOL is designed to require modest computer resources. For example, most solutions (10 cycles or less) can be accomplished in a few minutes on a personal computer.

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